DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

(6) STANDARDIZED WAVE AND WIND ENVIRONMENTS FOR NATO OPERATIONAL AREAS.

BY (9) Final rept.,

(10) SUSAN L. BALES
WAH T. LEE
[redacted]
JOYCE M. VOELKER

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

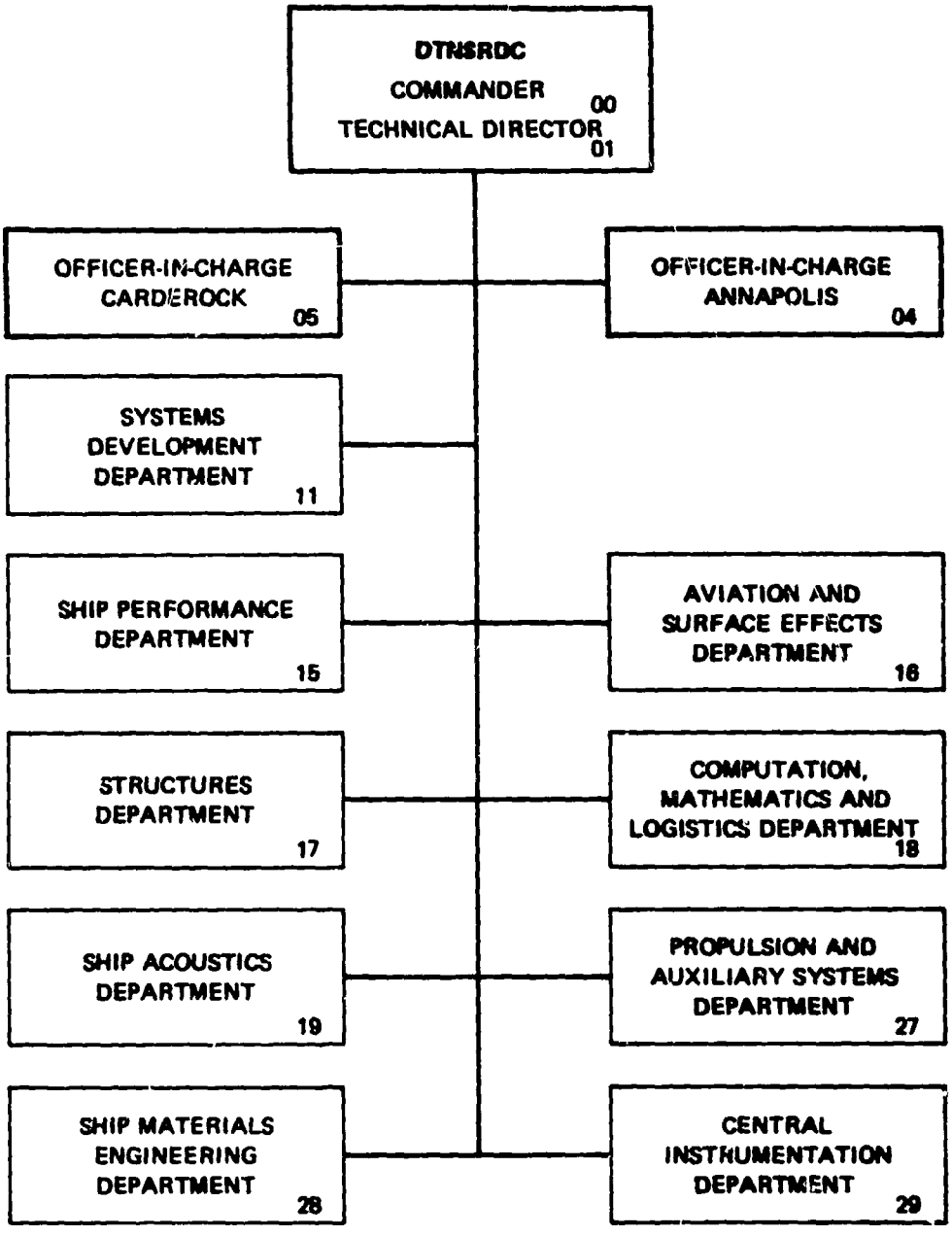
(16) F43421,
F59557

(17) ZF43421001,
SF59551695

SHIP PERFORMANCE DEPARTMENT

(11) JUL [redacted] 81 (12) 334 (14) DTNSRDC/SPD-0919-01

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



REPORT DOCUMENTATION PAGE

READ INSTR... BEFORE COMP...

1. REPORT NUMBER: DTNSRDC/SPD-0919-01
2. GOVT ACCESSION NO.: AD-A105 414
3. RECIPIENT'S CATALOG ...

4. TITLE (and Subtitle): STANDARDIZED WAVE AND WIND ENVIRONMENTS FOR NATO OPERATIONAL AREAS
5. TYPE OF REPO... & PERIOD COVERED: Final
6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): Susan L. Bales, Wah T. Lee and Joyce M. Voelker
8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Ship Performance Department
David W. Taylor Naval Ship R&D Center
Bethesda, Maryland 20084
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: (See reverse side)

11. CONTROLLING OFFICE NAME AND ADDRESS:
Naval Sea Systems Command, Washington, D.C. 20362
Naval Material Command, Washington, D.C. 20360
12. REPORT DATE: July 1981
13. NUMBER OF PAGES: 336

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Natural Environment
Spectral Ocean Wave Model (SOWM)
Hindcast
NATO
Ship Performance
Wave Spectra
Wave Statistics
Standard Agreement (STANAG)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is a source document for specifying wind and wave conditions for those regions considered appropriate for joint operations of NATO naval forces. The areas considered are the North Atlantic Ocean northward from the Tropic of Cancer, the Mediterranean Sea, and coastal or landlocked areas such as the North, Baltic and Black Seas. The report provides seasonal and geographic distributions of wind and wave parameters and specifies mathematical

(Continued on reverse side)

(Block 10)

Program Element 62543N and 62759N
Project ZF 43 421 001 and SF 59 557 695
Work Unit Numbers 1568-323-01, 1500-104-26, 1568-838-03, 1500-300-37

(Block 20 continued)

models by which wave spectra, required by any ship seakeeping performance methodology, can be developed. Portions of the data contained herein are derived from the U.S. Navy's emerging Twenty Year Hindcast Wind and Wave Climatology, and are considered to be far superior to data previously available for those operating areas.

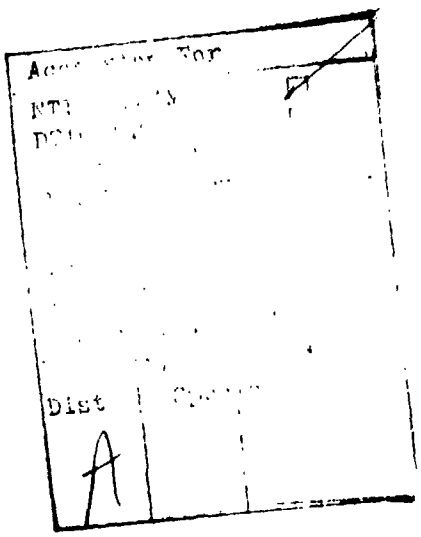


TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This report is a source document for specifying wind and wave conditions for those regions considered appropriate for joint operations of NATO naval forces. The areas considered are the North Atlantic Ocean northward from the Tropic of Cancer, the Mediterranean Sea, and coastal or landlocked areas such as the North, Baltic and Black Seas. The report provides seasonal and geographic distributions of wind and wave parameters and specifies mathematical models by which wave spectra, required by any ship seakeeping performance methodology, can be developed. Portions of the data contained herein are derived from the U.S. Navy's emerging Twenty Year Hindcast Wind and Wave Climatology, and are considered to be far superior to data previously available for those operating areas.

ADMINISTRATIVE INFORMATION

This report was prepared under the sponsorship of the Naval Sea Systems Command (NAVSEA), Code 3213 Work Request Number WR91589, the Ship Performance and Hydromechanics Program funded under Program Element 62543N and Block Number ZF 43 421 001, and the Surface Wave Spectra for Ship Design Program under Program Element 62759N and Project Number SF 59 557 695. It is identified by Work Unit Numbers 1568-823-01, 1500-104-26, 1568-838-03, and 1500-300-37 at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC).

BACKGROUND

In 1978, NATO Information Exchange Group 6 (IEG/6), Sub-Group 5 (SG/5), whose purpose is to develop a Standard Agreement (STANAG) between NATO nations for assessing destroyer and frigate seakeeping properties, identified the need to also develop a STANAG which provides the appropriate natural environment inputs to the seakeeping methodology and provides a standard for observing sea conditions during NATO ship trials or operational evaluations. The U.S. delegate to the sub-group volunteered to explore such an effort, and a tentative approach was proposed to the group at the April 1979 meeting held at DTNSRDC in Bethesda, Maryland. The approach was subsequently approved, and this report has been developed as the source document of wave and wind statistics required to develop the STANAG.

APPROACH

The procedure followed is broken into four succinct steps. They are

1. Define operational areas
2. Develop wind and wave statistical data bases
3. Develop wave spectral families
4. Show sample methodology application

The definition of operational areas is straightforward and dependent only upon the proximity and geographic locations of the NATO nations. Figure 1 identifies the three generic operational areas that are readily identifiable. They are

1. Open ocean North Atlantic from the Tropic of Cancer northward
2. Mediterranean Sea
3. Coastal and landlocked waters (e.g., North, Baltic and Black Seas)

As the statistical data bases and the wave spectral families appropriate for each area may vary, subsequent sections of this report deal with each region separately. The data for each region is provided in Appendices A to E. Appendix F provides a description of the data formats which have been employed. Appendix G provides the relative wind envelopes for VTOL aircraft operations. Appendices H and I provide computer FORTRAN subroutines for calculating the recommended wave spectra for each operational area.

OPEN OCEAN NORTH ATLANTIC

WAVE AND WIND STATISTICS

The open ocean region identified on Figure 1 spans the North Atlantic from the latitudes of the Northeast Trade Winds (up to about 30° N) through those of the prevailing Westerlies (30 - 60° N) and into the Polar Northeasterlies (above 60° N), so that it is not surprising that the climatology of the operational area is strongly a function of northerly location or latitude. Additionally, the influence of land mass, currents, continental shelf, and local storm tracks each cause a similar climatology variation with longitude. Therefore, it is considered appropriate to divide the open ocean area into sub-areas which are identified in Figure 2. Because of the previous wide usage of the wave statistics provided by Hogben and Lumb, see Reference 1*, it was decided to adopt their definition of geographic zones where

*A complete listing of references is given on pages 13 and 14.

possible. Areas 1, 2, 3, 4, 6, 7, 8, 9, 10, and 11 are taken as defined by Hogben and Lumb. Areas 15, 16, 17, and 18 are also taken as defined by Hogben and Lumb but truncated at the Tropic of Cancer (23° N). Areas 00 and 0 are new areas which have been added to span the more northerly operational regions.

While Reference 1 provided the previous standard for developing wave statistics for the North Atlantic Basin, a new data base is now emerging which will become a primary source of environmental data for ship seakeeping analyses. This new data set has been under development by the U.S. Navy since 1976, and as it is well treated in Reference 2, will only be briefly described here.

In short, the Spectral Ocean Wave Model (SOWM), documented in Reference 3 and based on the work of Pierson and his associates, see Reference 4, is being used to hindcast wave conditions throughout the Northern Hemisphere. The model utilizes archived and well-refined wind fields, see Reference 5, from which directional wave spectra are hindcast at six-hour intervals for a continuous period of 20 years. The hindcasts reflect the propagation of wave energy from one location to another as well as the growth and decay of the seaway with local winds.

A typical hindcast directional spectrum is given in Table 1. From the set of such spectra, a series of parameters are derived which provide a simple summary of the character (height, period, and direction) of the seaway and which can be used to define families of representative wave spectra. As the wind speed and direction is carried along with the data set, joint distributions of wind and wave parameters are also constructed.

The darkened circles about the grid points within each area on Figure 2 indicate the SOWM grid points included in this work. Ultimately the data may be expanded to include at least the circled grid points. Table 2 provides a summary of the points currently included. The parameter sets that are developed are

1. Significant wave height vs. modal wave period
2. Significant wave height vs. wind speed
3. Significant wave height vs. primary wave direction
4. Wind speed vs. wind direction
5. Significant wave height vs. wind speed (using World Meteorological Organization Standard Sea State definition)
6. Persistence of significant wave height
7. Persistence of significant wind speed

Other parameter distributions (e.g., primary spectral width vs. primary wave direction, primary wave direction vs. secondary wave direction, directional spread about primary wave direction vs. directional spread about secondary direction) can be added to this source document as computer resources permit. While these data distributions are developed for the ten year period from September 1959 to August 1969, it is noted that seasonal parameter distributions are also of interest and should be utilized in the seakeeping performance assessment methodology.

Appendix A provides the data base of open ocean wind and wave conditions derived from the Ten Year Hindcast Wind and Wave Climatology. Tables are provided for areas identified in the North Atlantic open ocean region. Areas included are provided in Table 2. Both annual and seasonal distributions are provided. In keeping with Reference 2, the seasons are defined by

1. Winter - December to February
2. Spring - March to May
3. Summer - June to August
4. Fall - September to November

However, an ongoing evaluation of a dynamic season definition (for example, of varying length for each year) may indicate the need to revise these definitions of season at a later time. Figure 3, from Reference 2, illustrates the seasonal variation of mean significant wave height at the selected location in Area 2. Clearly, the duration of more severe conditions can occur at varying times in different yearly cycles. Therefore, cumulating data for a fixed calendar span (e.g., all December to Februarys) would produce a somewhat different worst season than if a sliding seasonal definition were used.

Figure 4, from Reference 2, provides a comparison of some of the newly developed Area 2 (grid point 127) data with that provided previously by Reference 1. This latter data has been converted from observed to significant values by application of the Nordenström relationship* described in a draft "Sea Environment Manual for Ship Design"** and developed in Reference 6. The wave height occurrences for grid point 127, if taken collectively over the ten year sample, are fairly typical for the

---

*The Nordenström relationship is given by

$$(\zeta_w)_{1/3} = 1.68\ (\zeta_{obs})^{0.75} \quad \text{meters}$$

**Report DTNSRDC/SPD-0720-01 to be published in 1982.

entire region bounded by Area 2. The hindcast data set is without fair weather and observer skill biases which may be at least partially surmised from the figure. For example, the hindcast data set provides a greater statistical occurrence of all waves exceeding about 2 meters. The highest significant wave height in this ten year sample of hindcasts is 17.8 meters and the correspondong mode of the directional spectrum is about 23 seconds. On the other hand, the highest observed wave in the Hogben-Lumb sample is about 12.8 meters and its observed mode is between 10 and 11 seconds. Clearly, the hindcast data set provides the naval architect with important new wave statistics which will hopefully improve the realism of seakeeping performance assessments. It is noted that the modal periods developed in this work are reflective of the peak of the primary direction of the (density) directional spectrum. Very often this coincides with the peak of the primary direction as well as the entire spectrum.

With regard to wave periods, the hindcasts generally indicate longer wave periods for given heights. This is not surprising as it is difficult to observe them at sea and even the codes used to record observed occurrences on board ship are inadequate in this regard. Very often, the naval architect uses the most probable modal or peak wave period for several varying wave heights. In this work, the modal periods, being longer, will cause larger responses to be calculated for the longer ships. Figure 5 shows a comparison of the new (tentative) most probable period - significant wave height relationship with tne previously used one recommended in the "Sea Environment Manual for Ship Design." Clearly, for waves in excess of about 6.5 meters, the hindcast periods are from 0.5 to 3 seconds longer.

Without doubt, the most severe wave conditions which NATO fleets will encounter are in the North Atlantic. Figure 6 presents an annual comparison of significant wave height occurrences for the five generic operational areas. As might be expected, the North Sea is ranked second most severe with the Black Sea third, the Mediterranean Sea fourth, and the Baltic Sea fifth. When only worst seasons are compared the ranking is the same as for the annual occurrences, see Figure 7.

Figures 8 and 9 provide a more detailed illustration of annual and worst season occurrences for the areas defined in Table 2 in the North Atlantic. These data are based on the occurrences provided in Appendix A. Gene ally, the severer conditions prevail between 50 and 60° N with the western portions indicating somewhat worsened conditions.

Figure 10, from Reference 2, defines regions of extreme seas in the North Atlantic. Extreme seas are defined to be those with significant wave heights of 10 meters or more. The figure was constructed by tabulating all extreme occurrences for the circled 65 grid points in the ten year sample. Clearly, ship operations conducted between about 55 and 60° N will generally encounter more severe conditions, though occasional occurrences are noted as far south as the Tropic of Cancer.

WAVE SPECTRAL FAMILY

In keeping with the recommendations of the International Ship Structures Congress (ISSC) and the International Towing Tank Conference (ITTC), as well as current U.S. Navy design practice ("Sea Environment Manual for Ship Design"), the two-parameter Bretschneider spectral formulation is recommended for use for the open ocean North Atlantic. The spectrum can be written in the form

$$S_\zeta(\omega) = A\omega^{-5} \exp[-B/\omega^4] \quad m^2 \text{ sec}$$

where $$A = 483.5\ (\tilde{\zeta}_w)^2_{1/3}/T_o^4 \quad m^2/\text{sec}^4$$

and $$B = 1944.5/T_o^4 \quad 1/\text{sec}^4 \qquad (1)$$

The two defining parameters of the spectrum are the significant wave height, $(\tilde{\zeta}_w)_{1/3}$, in meters and the modal or peak wave period, T_o, in seconds. The parameters can be taken from the data base provided in Appendix A, see Appendix F for data format description. As indicated in the Appendix, the frequency distribution, being fixed in SOWM, permits only certain modal period values in the parameterization of the spectra. The periods are shown on Table 3 and are defined at the peak of the primary direction of the directional spectrum (converted to densities). Very often this peak occurs at the same frequency as that for the point spectrum and the total directional wave spectrum. Figure 11 provides a selection of Bretschneider spectra for the case when the significant wave height is defined as 0.30 m (1 ft).

The effect of wave directionality on predicted ship response can be substantial. Figure 12, from Reference 7, illustrates this effect for roll motion for a conventional destroyer hull. Uni-directional or long-crested seas permit much more severe motion, in the worst case, than multi-directional or short-crested seas. As short-crested seas occur most frequently in nature, it is recommended that they be used in

most seakeeping analyses. However, in certain investigations, e.g. of head sea pitch and heave motions, which require worst case values, long-crested seas should be used.

The state-of-the-art for modeling short-crested seas, is to apply a ±90 degree cosine squared spreading function to the individual frequency components of the uni-directional wave spectrum, for example see Equation (1). The function can be written

$$S_\zeta(\omega,\nu) = (2/\pi)\ \cos^2\ (\nu - \mu)\ S_\zeta(\omega) \qquad (2)$$

where ν represents the secondary wave directions, μ is the predominant wave direction and angles are measured in radians. In applying Equation (2), it is assumed that energy is constant across directional bands equivalent to the increment across successive ν's and that it is constant for all wave frequencies. The spreading function is generally applied about ±90 degrees and at 15-degree increments from the predominant wave direction. A generalization of this directionality model to a $\pm\nu^*$ cosine squared spreading function, see Reference 8, has been developed and may be applicable as more conclusions are derived from the Twenty Year Hindcast Climatology. For purposes of this report, it is recommended that the equation be applied for ±90 degrees, and at 15-degree increments. Effectively,

$$S_\zeta(\omega,\nu) = W \cdot S_\zeta(\omega)$$

and

$$W = \frac{\alpha}{\nu^*} \cos^2\ [\frac{90}{\nu^*}\nu - \mu] \qquad (3)$$

where angles are measured in degrees.

Table 4 provides values for W for various ν^* values. In this case, ν^* should be taken as 90 and α as 15, so that the W values under the "90" column are to be used.

Preliminary results reported in Reference 2 (for grid point 127 in Area 2) indicate that

1. Uni-directional seas are rare
2. Spreading using a cosine squared function about ±90 degrees may represent the most frequent case
3. Spreading as narrow as ±60 degrees and as broad as ±120 degrees is not rare

MEDITERRANEAN SEA

WAVE AND WIND STATISTICS

Wave and wind statistics for the Mediterranean Sea are provided in Appendix B for both annual and seasonal time spans. Frequencies of occurrence, developed from Reference 9, are provided for the three areas (29, 30, 31) identified on Figure 13. Parameters included are

1. Significant wave height vs. modal wave period
2. Significant wave height vs. wind speed
3. Significant wave height vs. primary wave direction
4. Wind speed vs. wind direction

The seasons are defined as for the open ocean North Atlantic case.

As indicated in Reference 2, the Twenty Year Hindcast Climatology will eventually be extended to include the Mediterranean Basin using an operational model, with a grid spacing of about 40 miles, currently in use by the U.S. Navy, see Reference 10. Hence, the data given in Appendix B will eventually be replaced with distributions similar to those of Appendix A. Additionally, the basin will be divided into operational areas such as is done in the North Atlantic.

WAVE SPECTRAL FAMILY

As the three Mediterranean areas noted on Figure 13 are in sufficiently deep water and with sufficiently long fetches, the Bretschneider Spectral Family discussed previously, should be used. In keeping with the range of values given in Appendix B, modal periods up to 13 seconds together with the appropriate significant heights, should be used to define the spectra. The same recommendations with regard to directionality as made for the open ocean are also applicable here.

COASTAL AND LANDLOCKED AREAS

WAVE AND WIND STATISTICS

Wave and wind statistics for coastal and landlocked operating areas are provided in Appendices C, D, and E.

Appendix C, developed from the Twenty Year Hindcast Climatology, provides data for the North Sea. Parameter distributions are similar to those provided for the open ocean in Appendix A and are for grid point 124 in Area 4 on Figure 2. A summary of some wave occurrences in this area is provided in Figures 6 and 7. The same

parameter sets and seasonal definitions as for the open ocean North Atlantic are also applicable here.*

Appendix D provides wave and wind statistics for the Baltic Sea, including the Gulf of Bothnia, which are derived from References 9, 11, 12, and 13. The specific operating areas included are noted on Figure 14. The same parameter sets and seasonal definitions as used for the Mediterranean are also applicable here.

Appendix E provides wave and wind statistics for the Black Sea derived from Reference 14. Figure 15 defines the specific operating area included. The eastern part of the Black Sea was not treated as the prevailing conditions there are less severe than the more western area shown in the figure. The parameter sets are the same as used for the Mediterranean while the seasons are defined as for the open ocean North Atlantic case.

WAVE SPECTRAL FAMILY

As all of these operating regions are relatively shallow** and at least partially surrounded by land, the Bretschneider spectral formulation is not recommended for use here. Instead, the mean JONSWAP spectrum is recommended here. This formulation was developed by Hasselmann in order to model fetch-limited, shallow water wave conditions, see Reference 15.

The JONSWAP spectrum is a generalization of the Pierson-Moskowitz form by inclusion of fetch as an additional parameter to wind speed. As it is usually written, the mean JONSWAP spectrum is dependent on the two parameters wind speed and fetch. However, for simplicity, as well as consistency with the current state-of-the-art in seakeeping performance assessment, a JONSWAP expression which is dependent only on the two parameters, significant wave height and modal wave period, is desirable. Such an expression is derived in Reference 16 and given by

$$S_\zeta(\omega) = \beta g^2 \omega^{-5} \exp\left[-1.25 \left(\frac{\omega T_o}{2\pi}\right)^{-4}\right] 3.3^{\exp\left[-\frac{1}{2\sigma^2}\left(\frac{\omega T_o}{2\pi} - 1\right)^2\right]} \quad m^2 sec \qquad (5)$$

---

*It should be noted that this Appendix will eventually be replaced by one consisting of hindcast data, under development by the German Navy, for a fine grid spacing throughout the North Sea.

**The Black Sea is actually of greater depth than the North or Baltic Seas, but no data have been found with which to determine the most appropriate wave spectral family.

where

$$\sigma = 0.07 \text{ for } \frac{\omega}{2\pi} \leq \frac{1}{T_o} \qquad (6)$$

or

$$\sigma = 0.09 \text{ for } \frac{\omega}{2\pi} > \frac{1}{T_o} \qquad (7)$$

and where ω is the circular wave frequency in radians per second. β is a constant dependent on the significant wave height, $(\tilde{\zeta}_w)_{1/3}$, and the modal wave period, T_o. β was developed to replace the α parameter given in the usual JONSWAP formulation and to correct for the parameter's nonuniversality. The inconsistency in the usual JONSWAP formulation arises for relatively high waves with long periods. Figure 16 provides an illustration of the difficulty for winds of 20 and 30 knots. The solid line represents the theoretical relationship between significant wave height and fetch for those wind speeds. The dashed line represents the values which are actually computed from the spectral area when the given fetch and wind speed are specified in the usual JONSWAP formulation. The difference between the solid and dashed lines represents a rather noticeable increase in significant wave height for fetches above about 40 nautical miles.

Figures 17 and 18 from Reference 16 permit the determination of β for given values of significant wave height and modal wave period. The wave parameter ranges are deliberately broad in anticipation of extreme occurrences which may be hindcast for the North Sea. The height and period ranges were determined by examination of the data sets in Appendices C, D, and E.

Figures 19 and 20 provide sample modified JONSWAP spectra for significant wave heights of 2, 3, 5, and 7 m and a range of modal wave periods. As is the case with the Bretschneider formulation, Equation (5) can be applied without special regard to fetch or wind speed. However, as those values could be of interest in some seakeeping analyses, Figures 21 and 22 are included to provide a comparison with corresponding height and period ranges.

As with the usual JONSWAP formulation, the modified expression given in Equation (5) is for long-crested seas. While there is limited experimental verification, the cosine squared spreading function is recommended for use with the JONSWAP spectral formulation at this time.

TOTAL MARINE ENVIRONMENT

The overall mission effectiveness of a naval ship is dependant on the total natural environment that the ship encounters.* While the functional relationships between the ship (including all of its combat and support systems) and the natural environment are not completely understood, some consideration of these factors may be appropriate. While this document emphasizes wave and wind phenomena, it is recognized that other environmental occurrences may be equally important to the ship's performance. Table 5, adopted from Reference 17, identifies a number of natural environment parameters that may impact performance of certain missions. In recognition of this, a summary table providing data for many of these parameters is given in Appendices A to E. The data, developed for annual occurrences, provides ranges of values expected for each parameter and is described in detail in Appendix F.

Figures 23 to 26, adopted from Reference 18, provide seasonal (February, May, August, and November) variations of surface currents (directional and speed) throughout the NATO operational areas. Limits of ice coverage are also indicated for more northerly latitudes.

EXTREME SEAS

The recommendations for the use of various wave spectral formulations generally reflect moderate to heavy weather operations (e.g., up to Sea State 6). Most naval missions to which this report is directed will be conducted in no more severe conditions than these. However, the occasion may arise when extreme conditions should be considered, particularly in the context of mobility mission requirements in the open ocean North Atlantic. For this case it is not clear whether the available Bretschneider or the JONSWAP spectral formulations are more appropriate. While Bretschneider spectra appear to be too broad (against frequency) and of insufficient peak definition, the JONSWAP formulation has not yet been well established as a model for extreme seas, particularly in the open ocean. What is more certain is that the directionality model associated with extreme seas should represent multi-directional, confused seas, see Reference 19. Future investigations will perhaps identify the more appropriate spectral formulation.

---

*Of course, it is also dependent on the man-made threat environment which is present.

ACKNOWLEDGMENTS

The Authors acknowledge the assistance of Mrs. Beverly Simon of DTNSRDC and Ms. Dottie McLean of ORI, Inc. in developing the graphs presented in the Appendices.

REFERENCES

1. Hogben, N. and F.E. Lumb, Ocean Wave Statistics, London, Her Majesty's Stationery Office (1967).

2. Cummins, W.E. and S.L. Bales, "Extreme Value and Rare Occurrence Wave Statistics for Northern Hemispheric Shipping Lanes," Proceedings of The Society of Naval Architects and Marine Engineers Spring/STAR Meeting (June 1980).

3. Lazanoff, S.M. and N.M. Stevenson, "An Evaluation of a Hemispheric Operational Wave Spectral Model," FNWC Technical Note 75-3 (June 1975).

4. Pierson, W.J., L.J. Tick and L. Baer, "Computer Based Procedures for Preparing Global Wave Forecasts and Wind Field Analyses Capable of Using Wave Data Obtained by a Spacecraft," in Sixth Naval Hydrodynamics Symposium, Washington, D.C., Office of Naval Research (1966).

5. Lazanoff, S.M. and N.M. Stevenson, "A Twenty Year Northern Hemisphere Wave Spectral Climatology," in Turbulent Fluxes Through the Sea Surface, Wave Dynamics, and Prediction, edited by A. Favre and K. Hasselmann, New York and London, Plenum Press (1978).

6. Nordenström, N., "Methods for Predicting Long Term Distributions of Wave Loads and Probability Failure for Ships, App II," Det Norske Veritas Research Department Report No. 69-22-S (1969).

7. Cox, G.G. and A.R. Lloyd, "Hydrodynamic Design Basis for Navy Ship Roll Motion Stabilization," Transactions of The Society of Naval Architects and Marine Engineers, Vol. 85, pp. 51-93 (1977).

8. Bales, S.L., E.N. Comstock, R.T. Van Eseltine and E.W. Foley, "Ship Seakeeping Operator Guidance Simulation," Proceedings of the Summer Simulation Conference (July 1979).

9. "U.S. Navy Marine Climatic Atlas of the World, Vol. 1, North Atlantic Ocean," Naval Weather Service Detachment Publication NAVAIR-50-1C-528 (1974).

10. Lazanoff, S.M. and N.M. Stevenson, "A Mediterranean Sea Wave Spectral Model," FNWC Technical Note No. 73-1 (Apr 1973).

11. Wahl, G., "Wave Statistics from Swedish Coastal Waters, Lightship Finn Grundet, Visual Observations," The Swedish State Shipbuilding Experimental Tank, Report No. 37 (Nov 1973).

12. Wahl, G., "Wave Statistics from Swedish Coastal Waters Lightship Falsterborer, Visual Observations and Measurements," The Swedish State Shipbuilding Experimental Tank, Report No. 38 (Nov 1973).

13. "Summary of Synoptic Meteorological Observations," U.S. Naval Weather Service Detachment, Asheville, N.C., Various Volumes (1970-1976).

14. The Winds and Waves at Oceans and Seas, U.S.S.R. Publication (1974).

15. Ewing, J.A., "Some Results from the Joint North Sea Wave Project of Interest to Engineers," International Symposium on the Dynamics of Marine Vehicles and Structures in Waves (Apr 1974).

16. Lee, W.T. and S.L. Bales, "A Modified JONSWAP Spectrum Dependent Only on Wave Height and Period," Report DTNSRDC/SPD-0918-01 (June 1980).

17. Bales, S.L. and E.W. Foley, "Atlas of Naval Operational Environments: The Natural Marine Environment," Report DTNSRDC/SPD-0795-01 (Sep 1979).

18. "Northeast Atlantic Environment Scenario," Naval Weather Service, Asheville, N.C. (Nov 1973).

19. Forristal, G.Z., E.G. Ward, V.J. Cardone and L.E. Borgman, "The Directional Spectra and Kinematics of Surface Gravity Waves in Tropical Storm Delia," Journal of Physical Oceanography, Vol. 8, No. 5 (Sep 1978).

20. "Instruction Manual for Obtaining Oceanographic Data," U.S. Naval Oceanographic Office, Publication No. 607, Third Edition (1968).

21. "Manual for Ship's Surface Observations," U.S. Naval Oceanography and Meteorology DIRNAVOCEANMETINST 3144.1A (12 Aug 1977).

22. "Guide to Meteorological Instrument and Observing Practices," World Meteorological Organization Publication No. 8, TP.3 (1971).

23. Schmitt, P., E.N. Comstock, S.L. Bales et al., "Sea Based Air Commissioned Ship Design Review Task: Seakeeping Assessment for CVN-71, CVA-67(MR), CVV, LHA-1, VSS-D, DDV-2, DDV-1D, DD-963, and SWATH-6," NAVSEA Report 3213-79-32 (Oct 1979).

24. "Preliminary Design Phase CVV Seakeeping Studies," NAVSEC Report 6136-78-13 (May 1978).

25. "Shipboard Helicopter Operating Procedures," NWP42 (Rev. D) (Dec 1977).

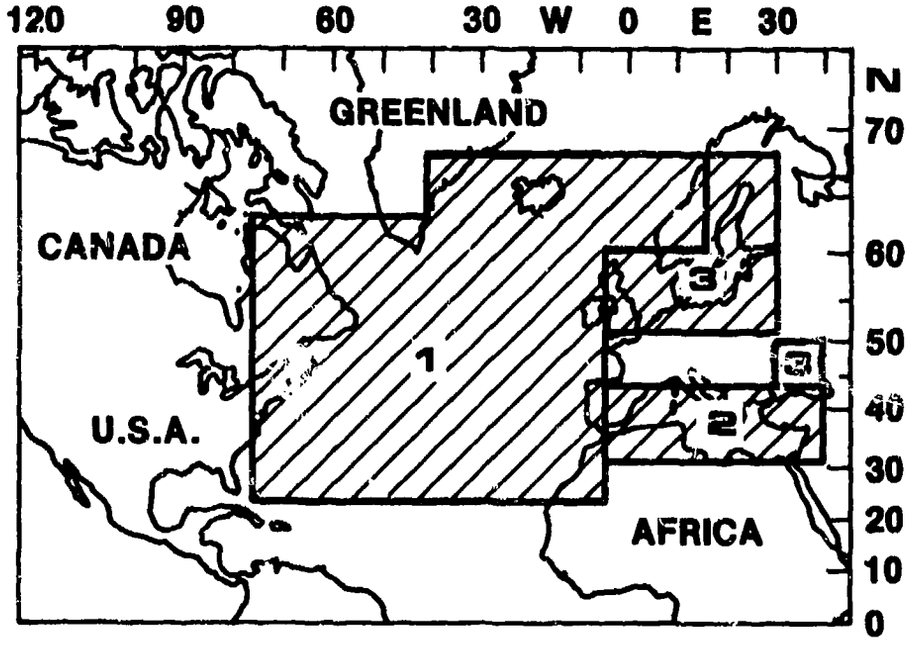


Figure 1 - Generic Naval Operational Areas for NATO Forces

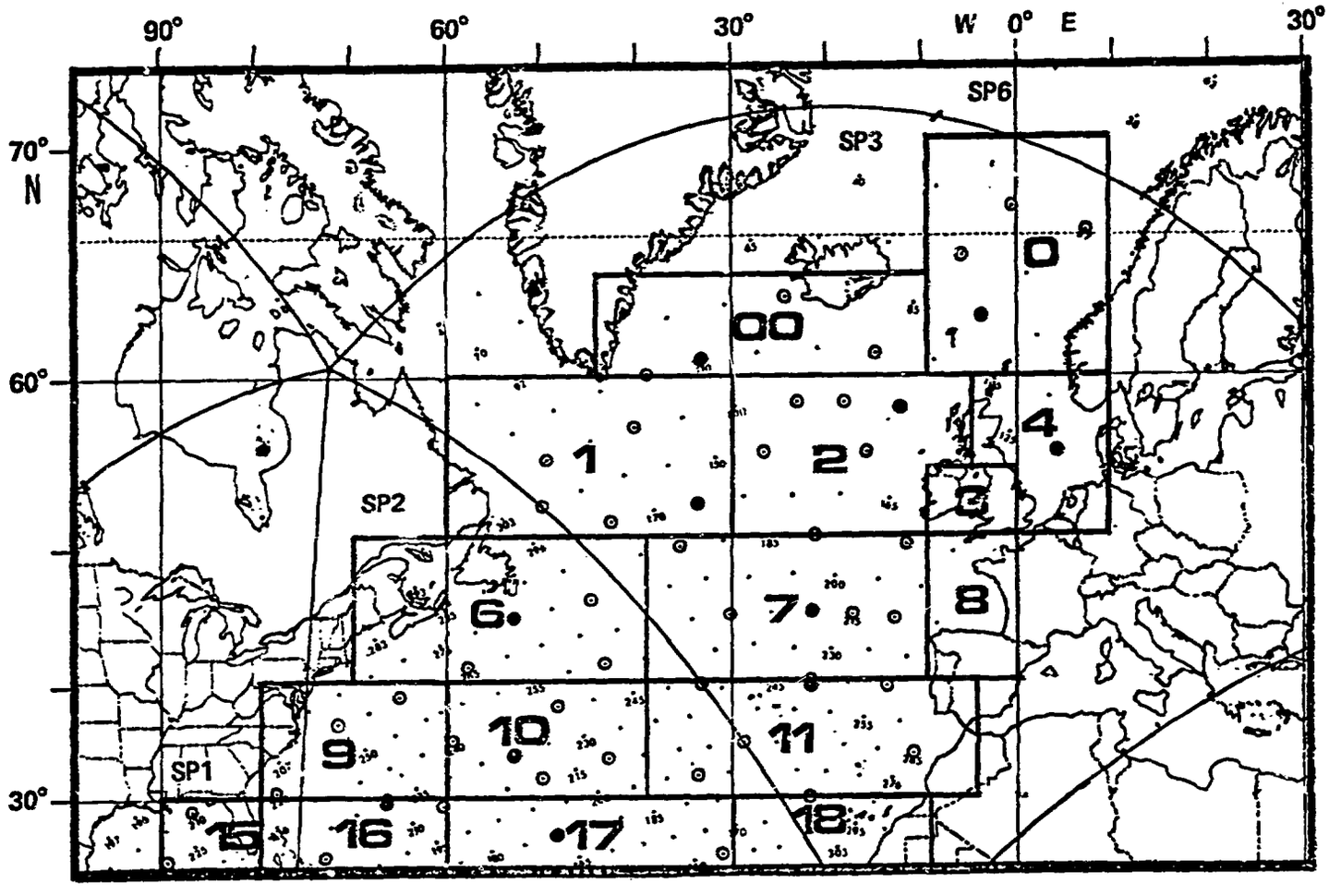


Figure 2 - Definition of Representative Areas in the North Atlantic Basin

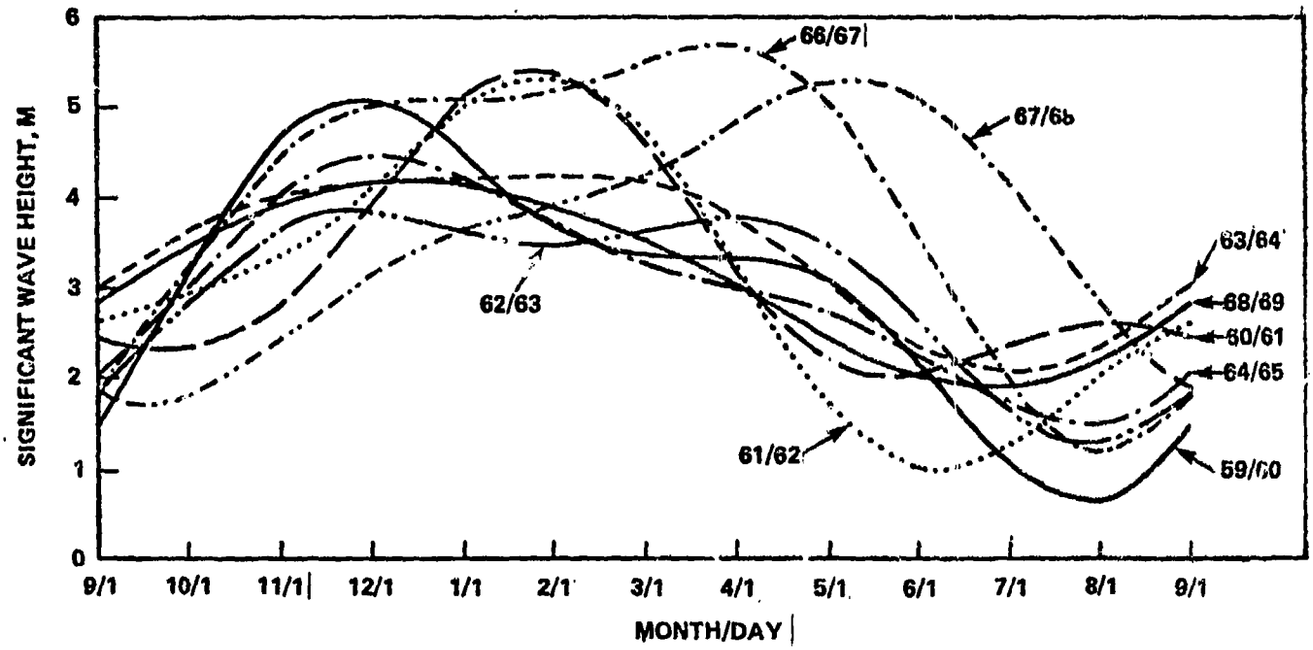


Figure 3 - Seasonal Variation of Significant Wave Height at Grid Point 127, Area 2, for Years 1959/60 to 1968/69 (Reference 2)

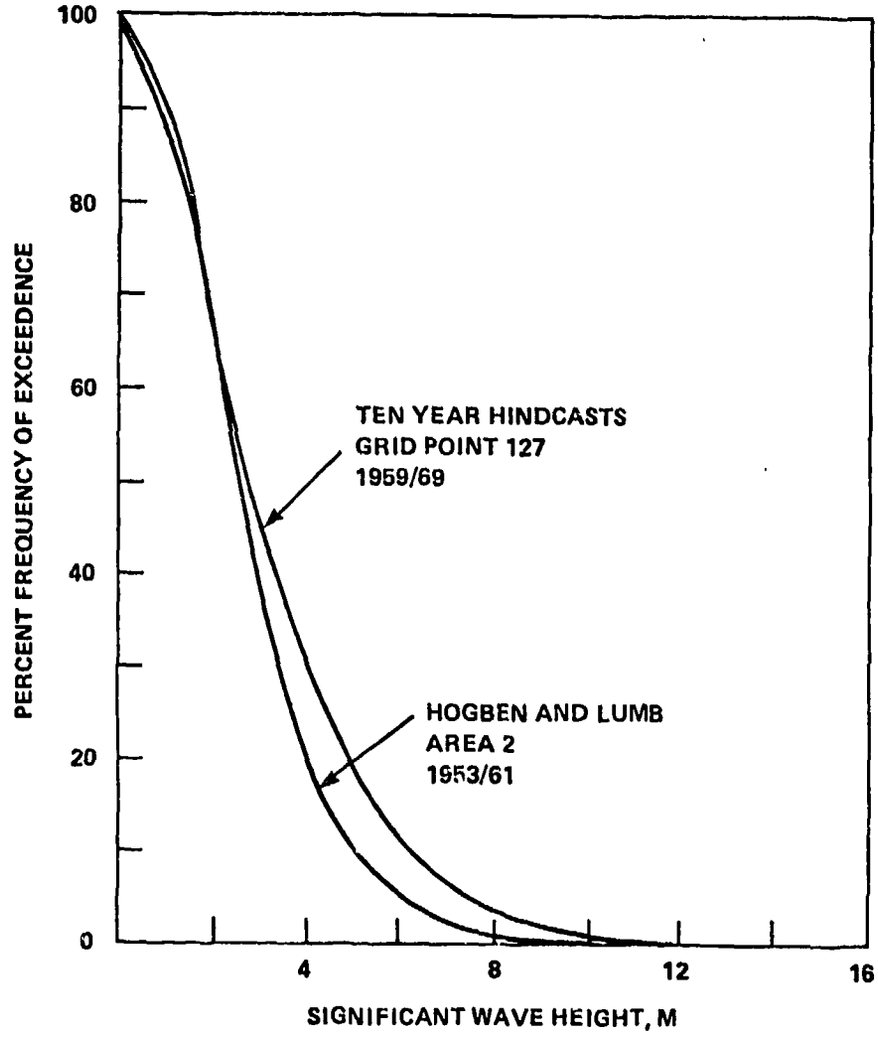


Figure 4 - Comparison of Hindcast and Observed Wave Height Occurrences (Reference 2)

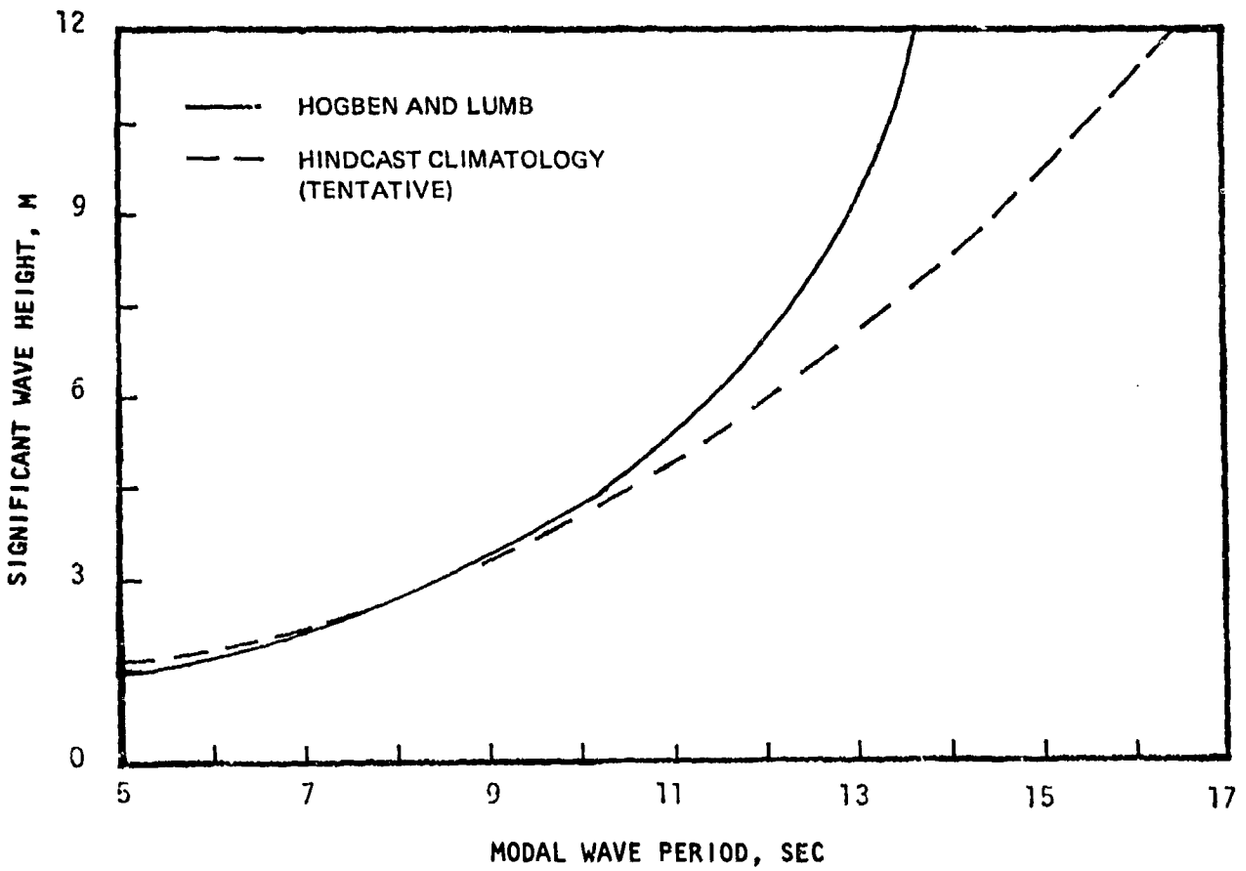


Figure 5 - Comparison of Hindcast and Observed Modal Periods, Given Height, for the North Atlantic Basin (Reference 2)

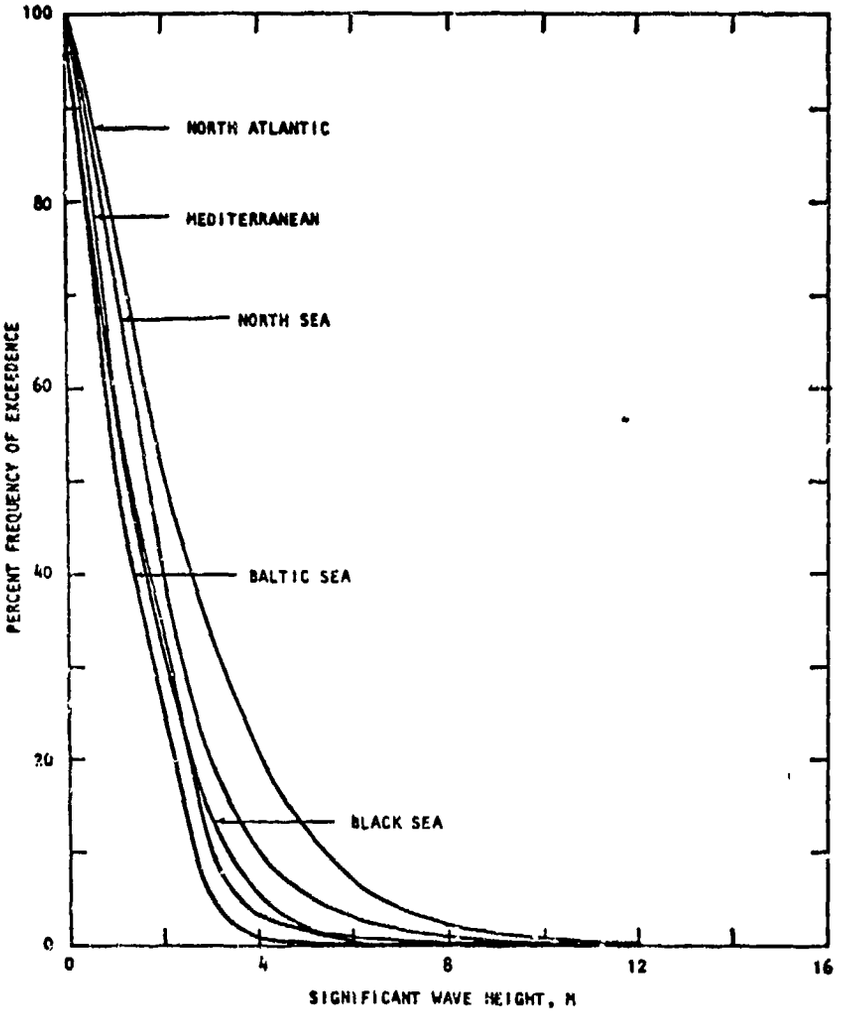


Figure 6 - Comparison of Annual Wave Height Exceedences of All Locations

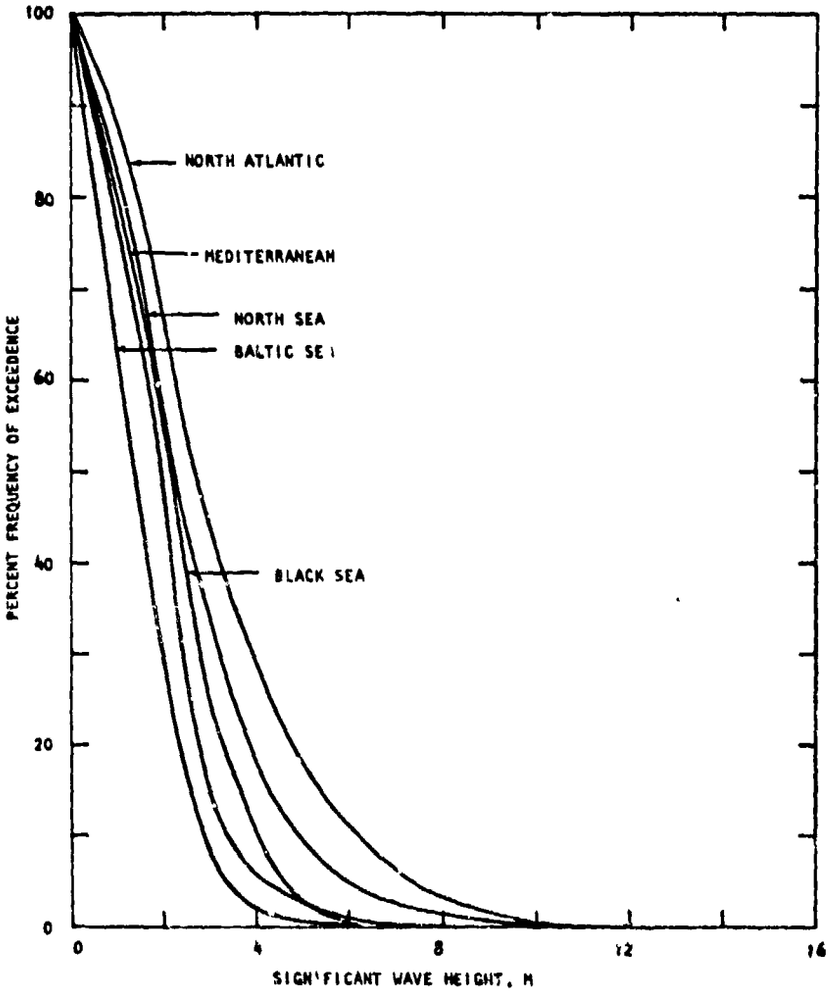


Figure 7 - Comparison of Worst Season Wave Height Exceedences of All Locations

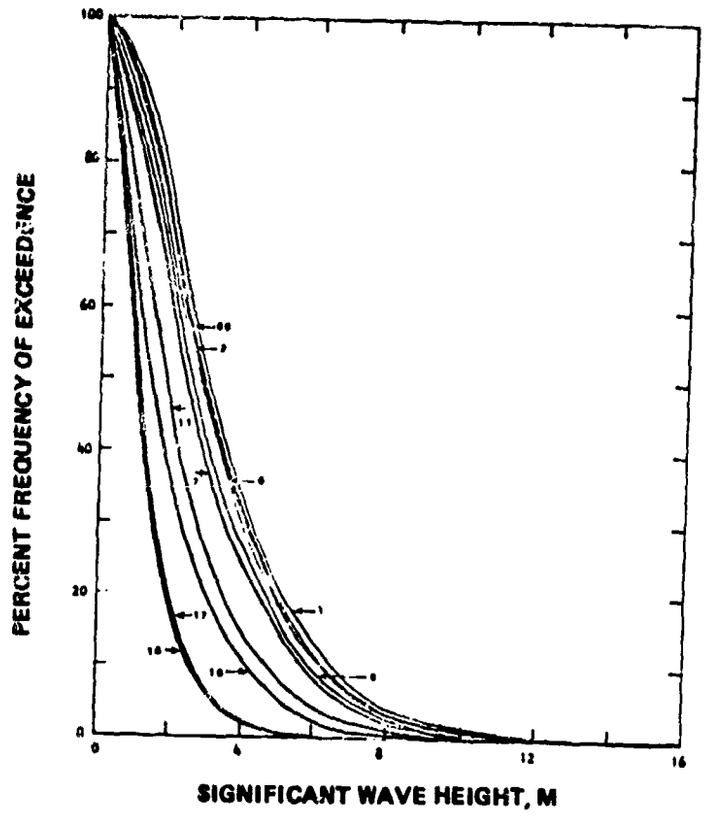


Figure 8 - Annual Significant Wave Height Exceedences
Hindcast for Selected North Atlantic Points
Defined on Table 2 for 1959 to 1969

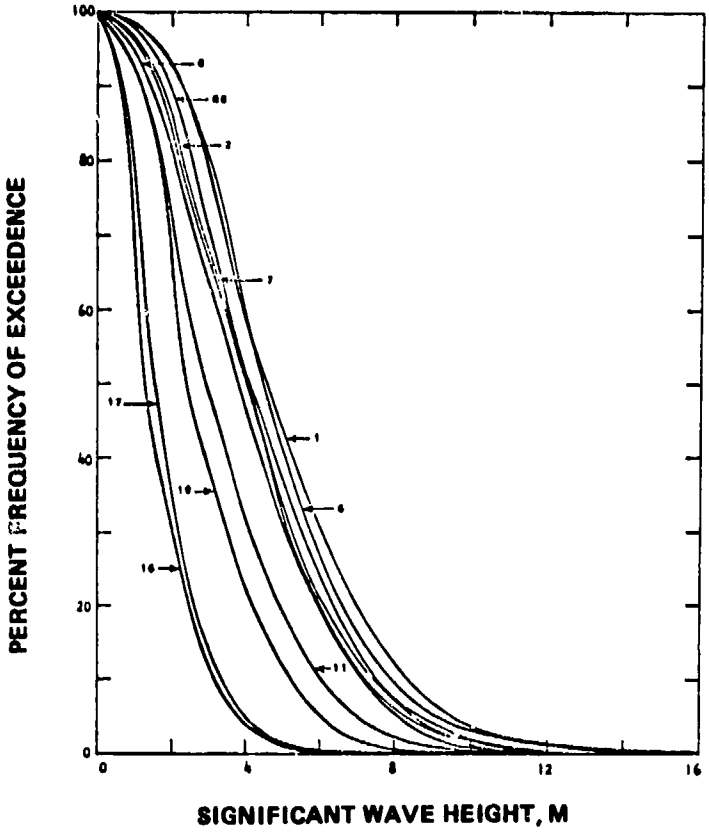


Figure 9 - Worst Season Significant Wave Height Exceedences Hindcast for Selected North Atlantic Points Defined on Table 2 for 1959 to 1969

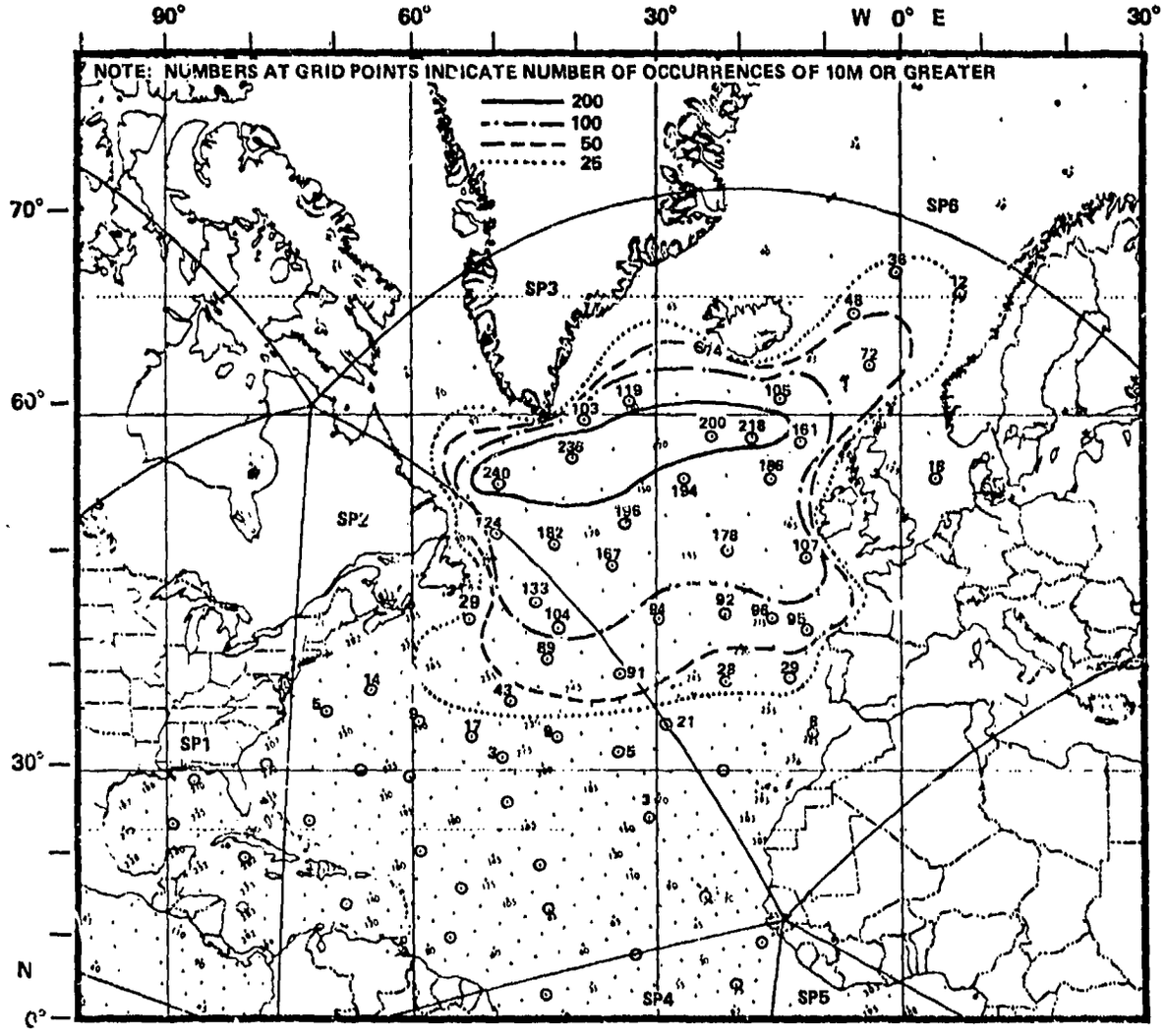


Figure 10 - Contours of 10 Meter or Greater Significant Wave Height Occurrences During 1959 to 1969 (Reference 2)

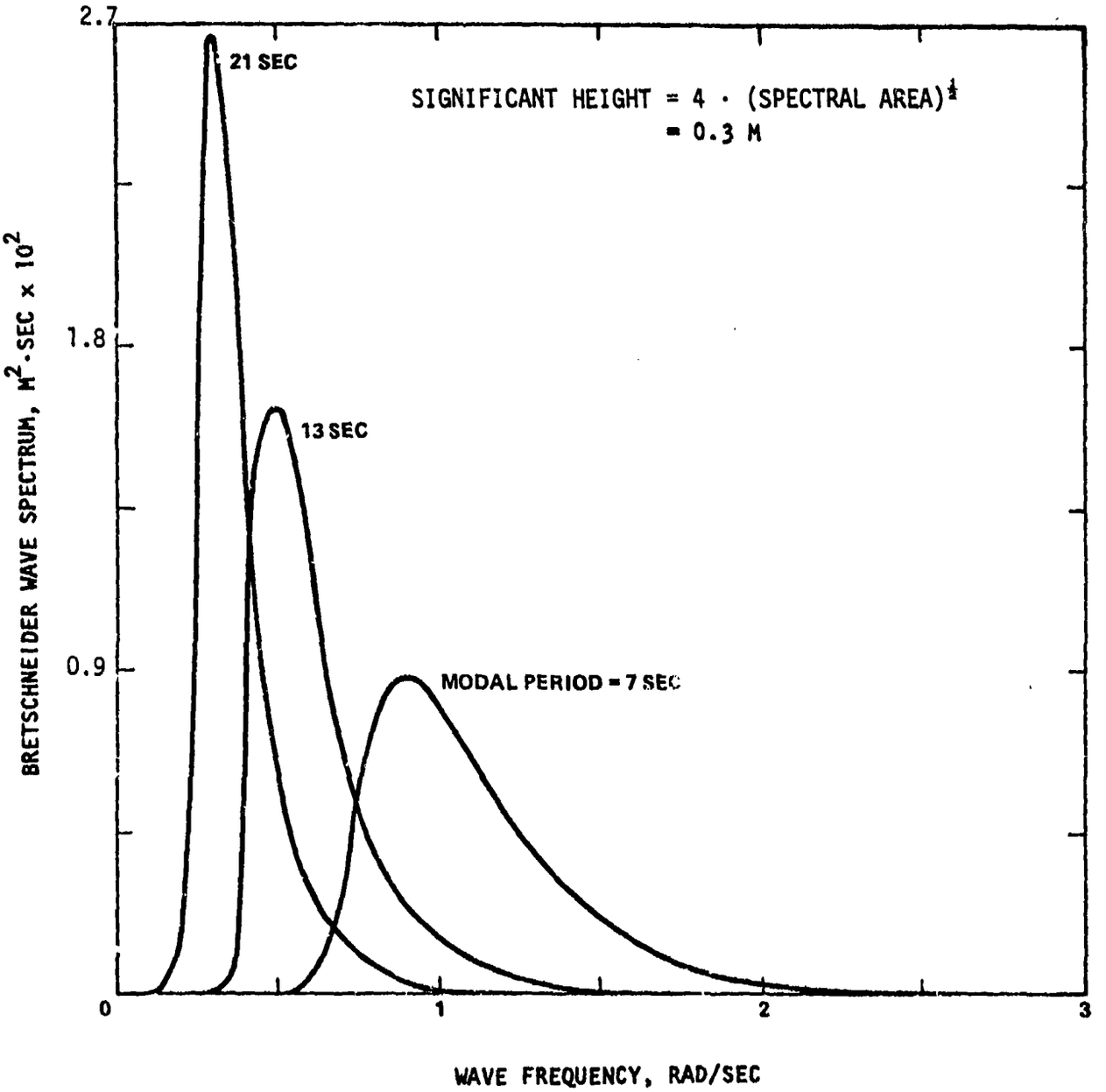


Figure 11 - Bretschneider Two-Parameter Spectral Family

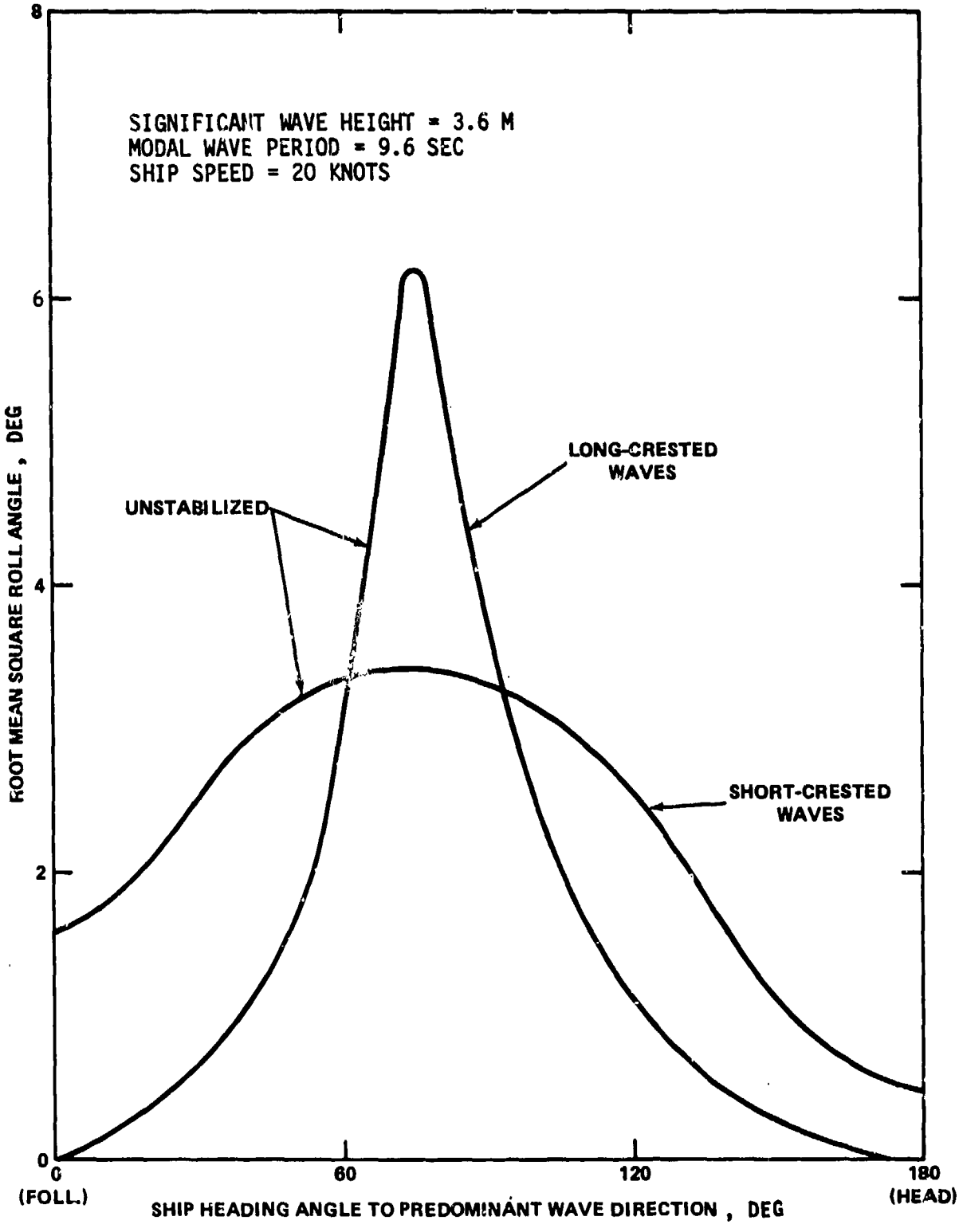


Figure 12 - Comparison of Roll Motion for Long- and Short-Crested Seas (Reference 7)

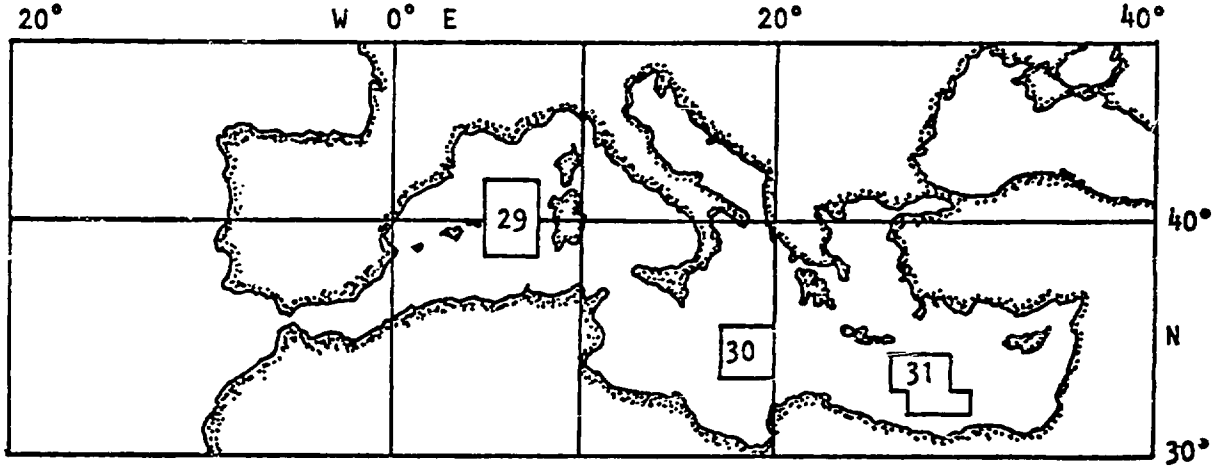


Figure 13 - Definition of Representative Areas in the Mediterranean Sea

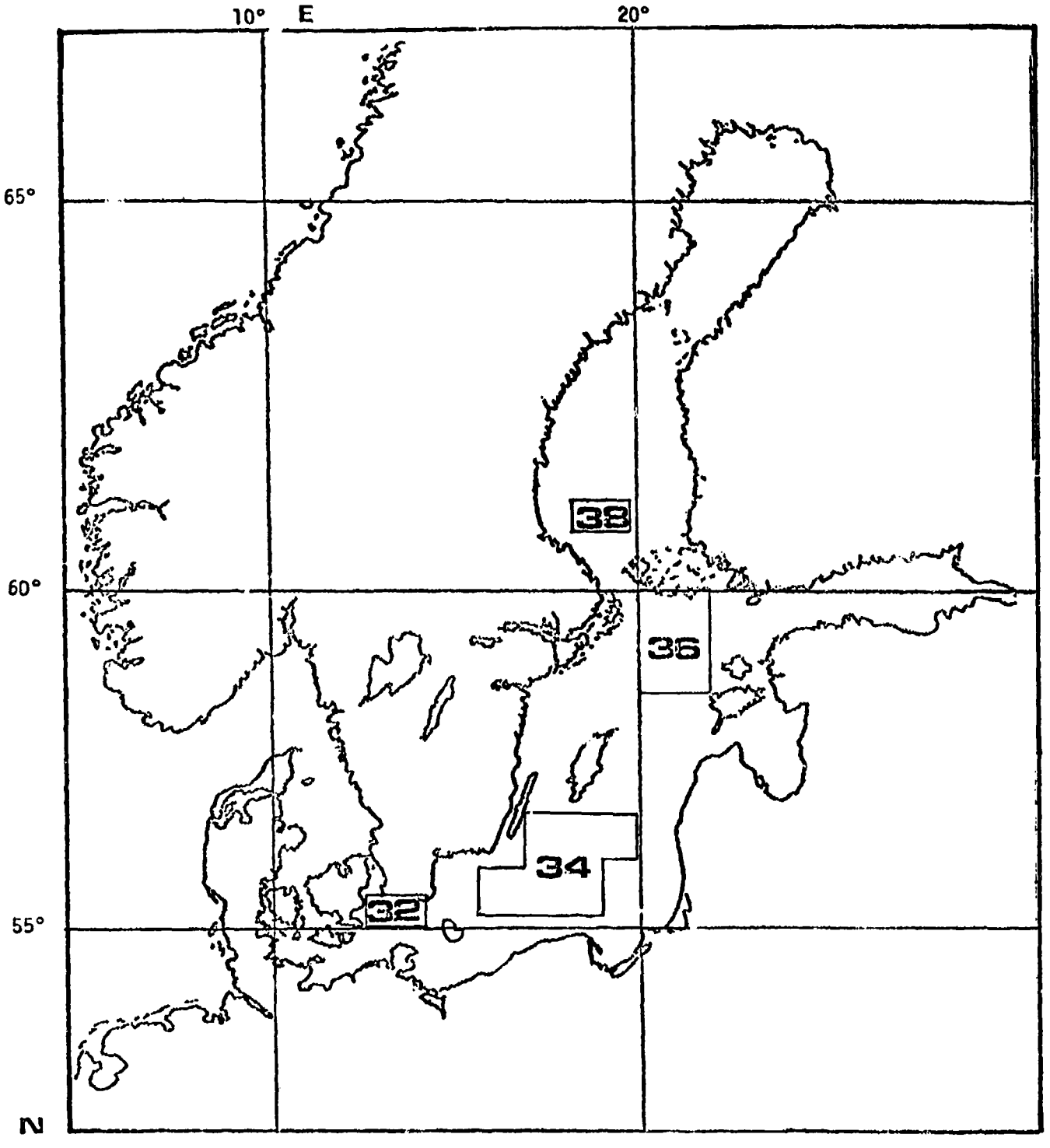


Figure 14 - Definition of Representative Areas in the Baltic Sea (Including Gulf of Bothnia)

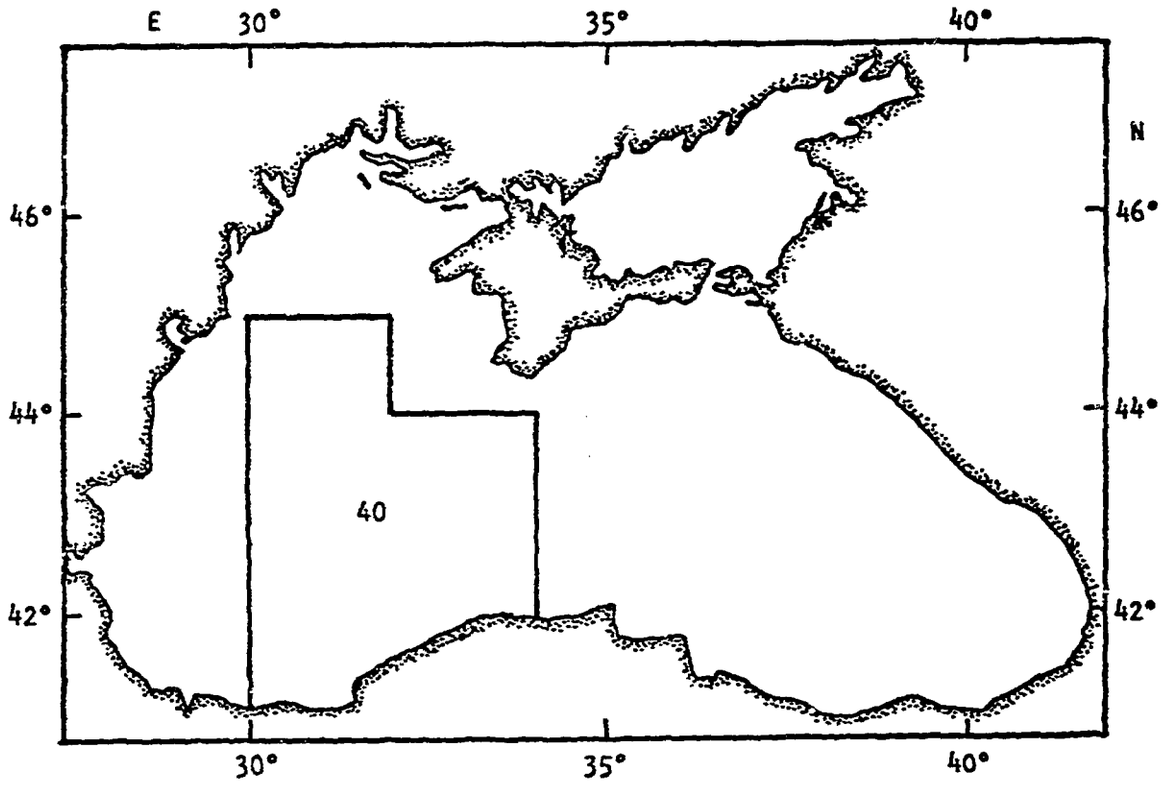


Figure 15 - Definition of Representative Area in the Black Sea

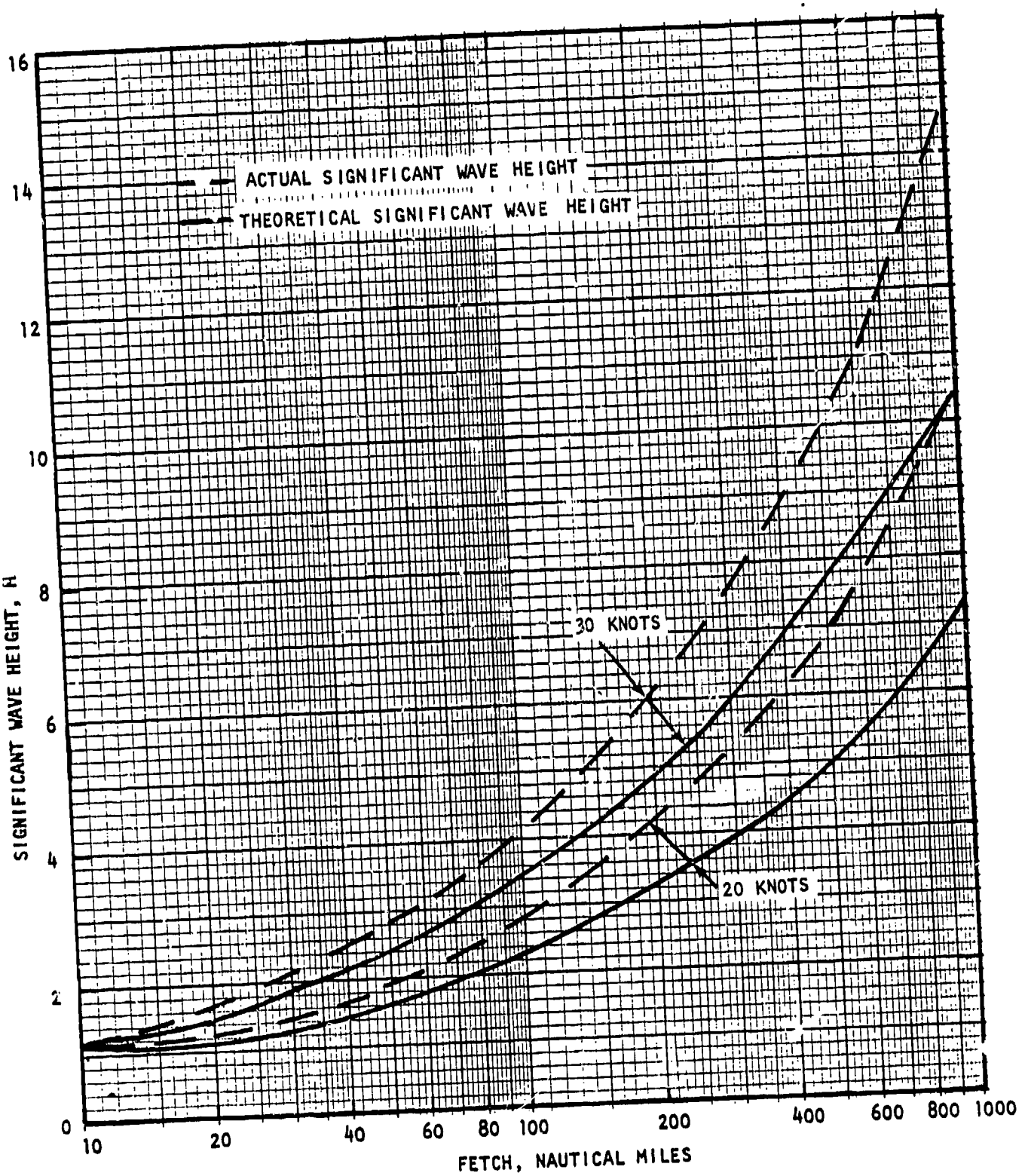


Figure 16 - Comparisons of JONSWAP Theoretical and Actual Significant Wave Height and Fetch Relationships (Reference 16)

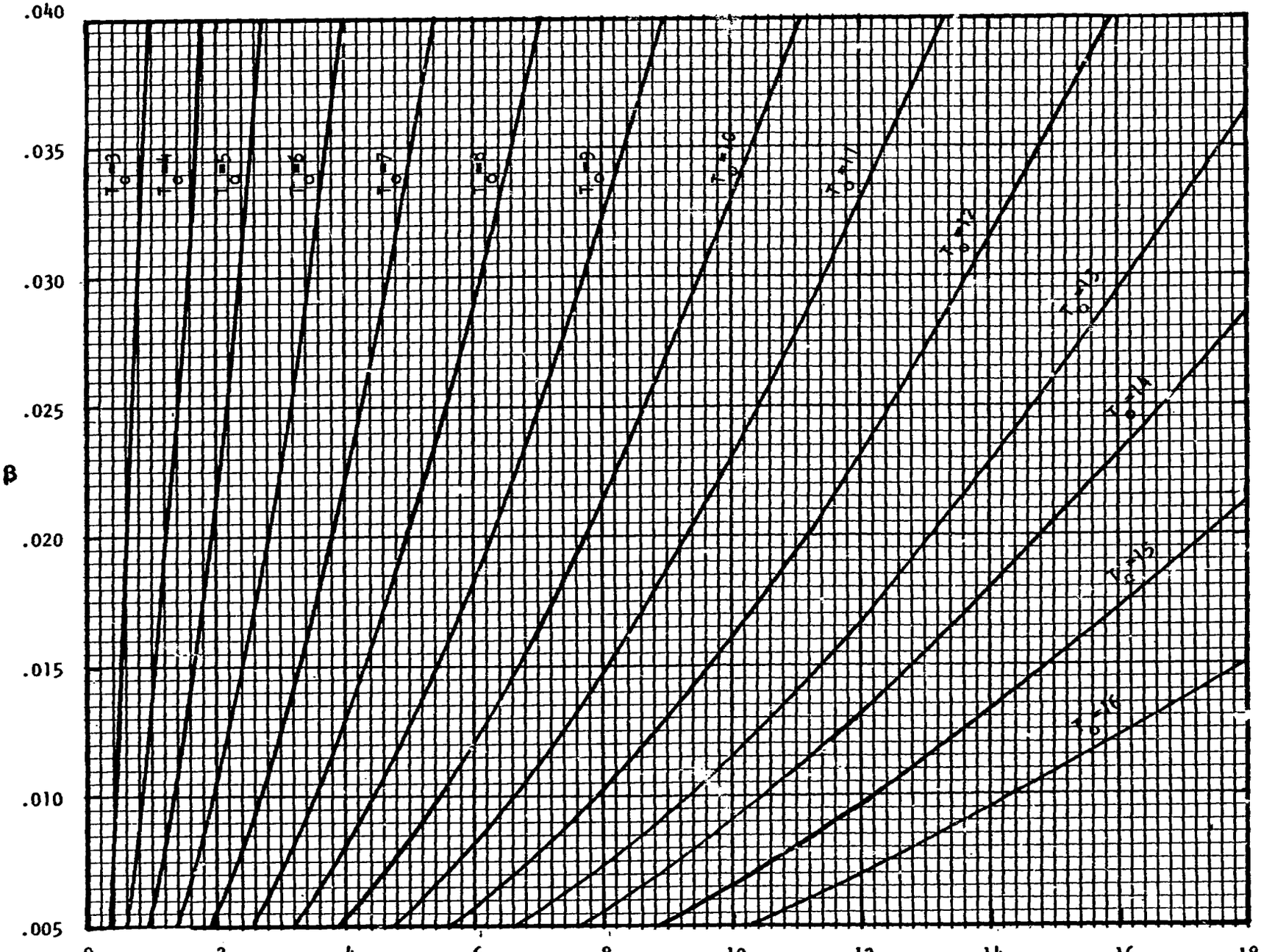


Figure 17 - Determination of β for Modified JONSWAP Spectrum (Reference 16)

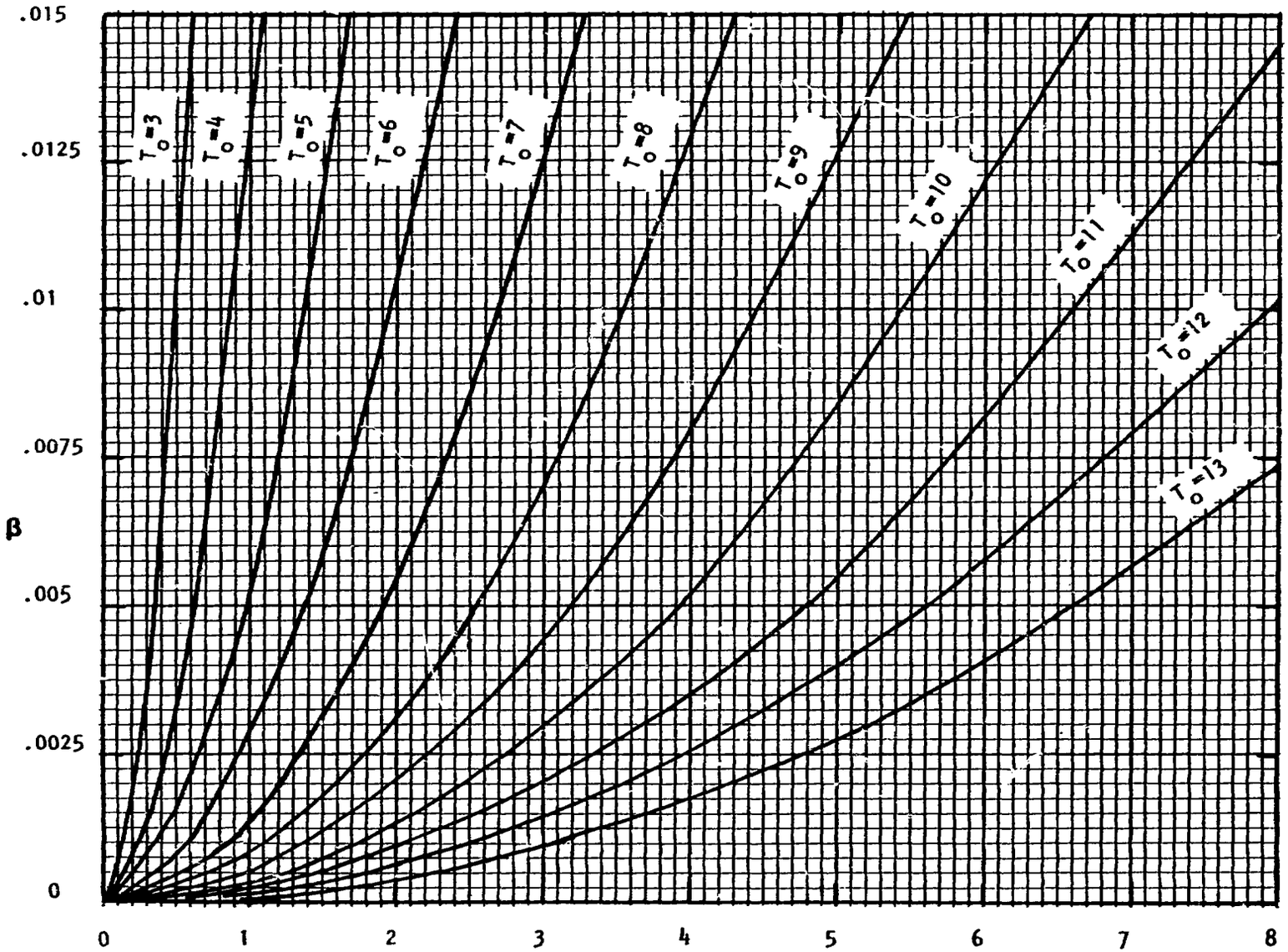


Figure 18 - Determination of Small β for Modified JONSWAP Spectrum (Reference 16)

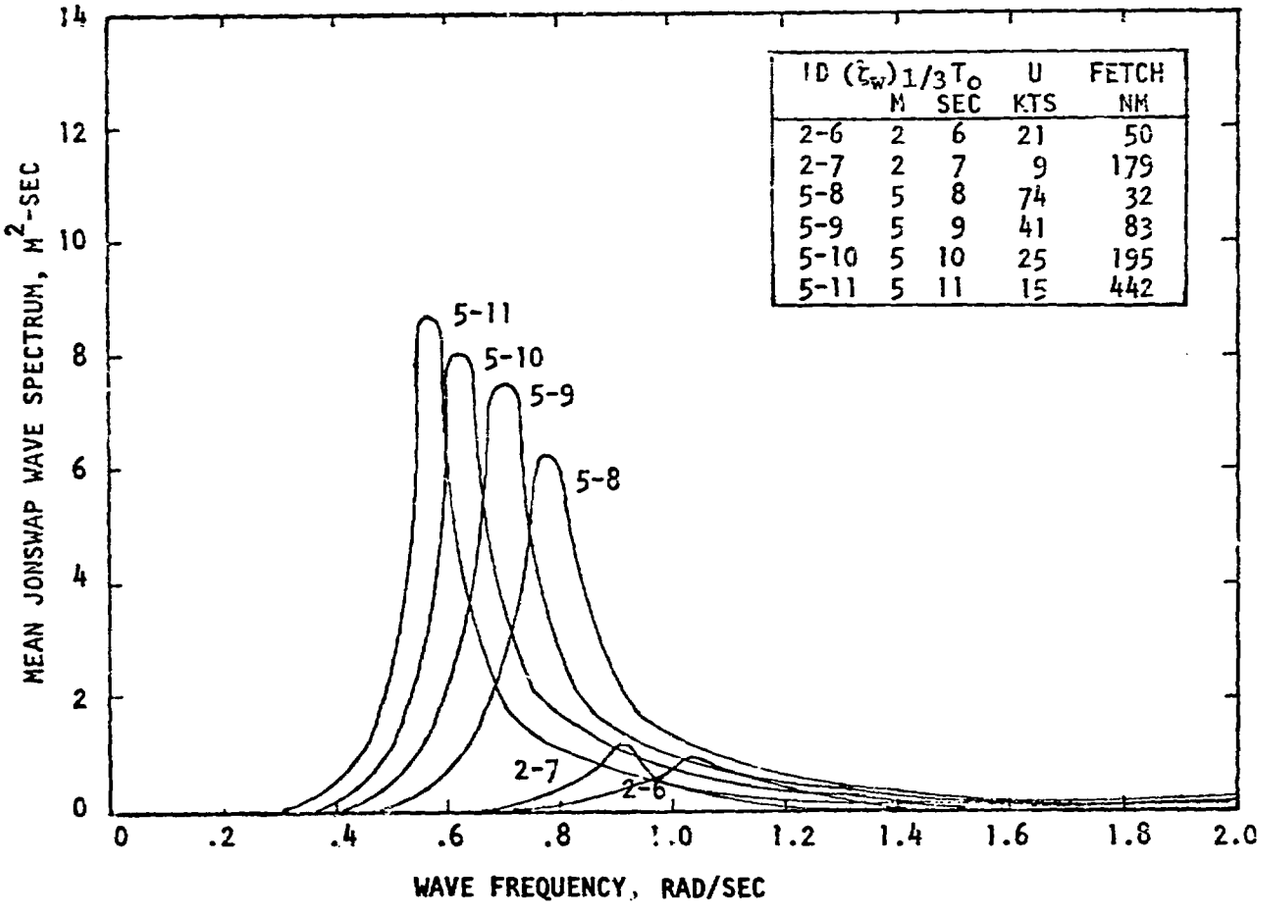
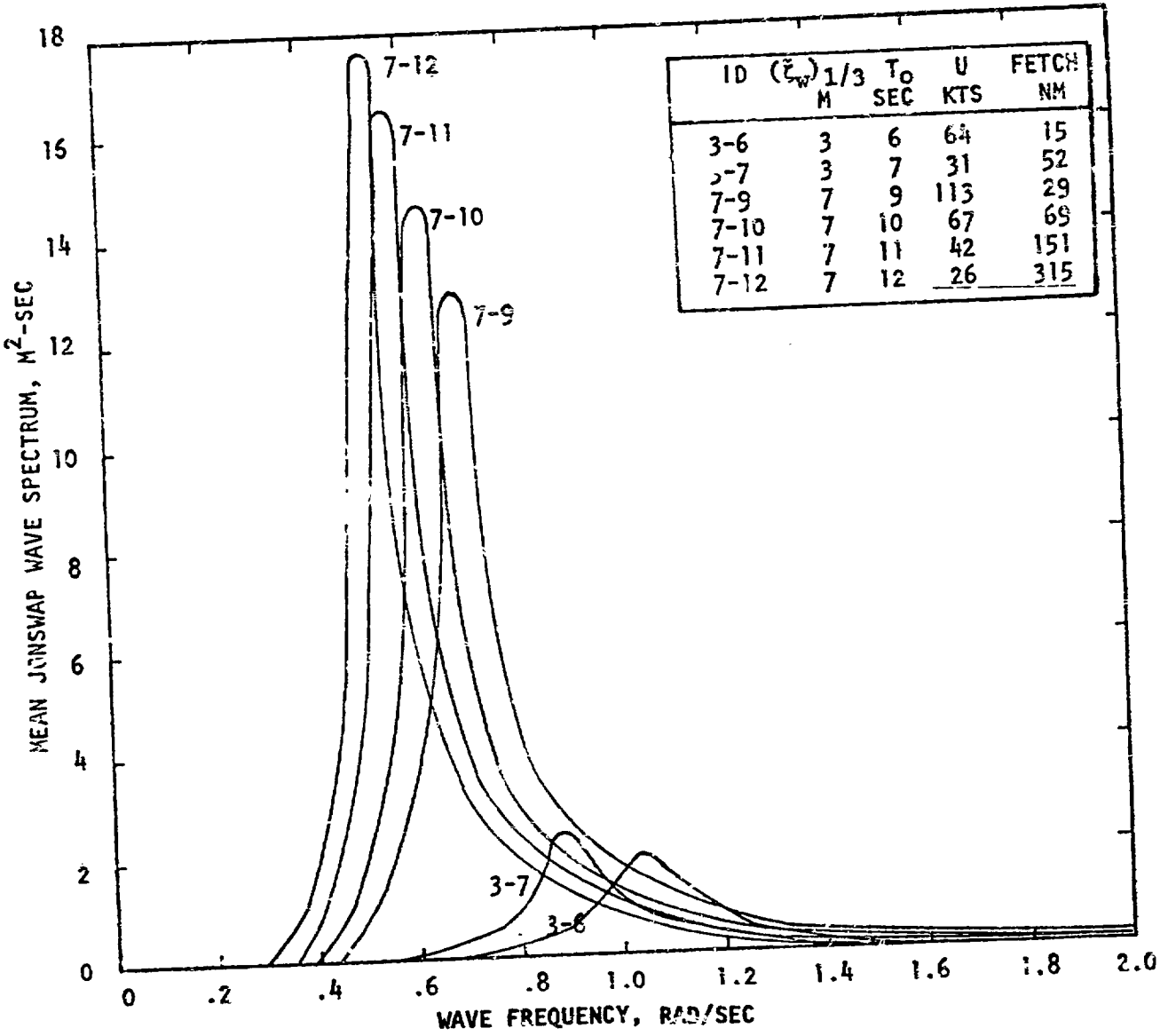


Figure 19 - Typical Modified JONSWAP Spectra for Significant Wave Height of 2 and 5 M (Reference 16)



ID	$(\tilde{\zeta}_w)_{1/3}$ M	T_o SEC	U KTS	FETCH NM
3-6	3	6	64	15
3-7	3	7	31	52
7-9	7	9	113	29
7-10	7	10	67	69
7-11	7	11	42	151
7-12	7	12	26	315

Figure 20 - Typical Modified JONSWAP Spectra for Significant Wave Heights of 3 and 7 M (Reference 16)

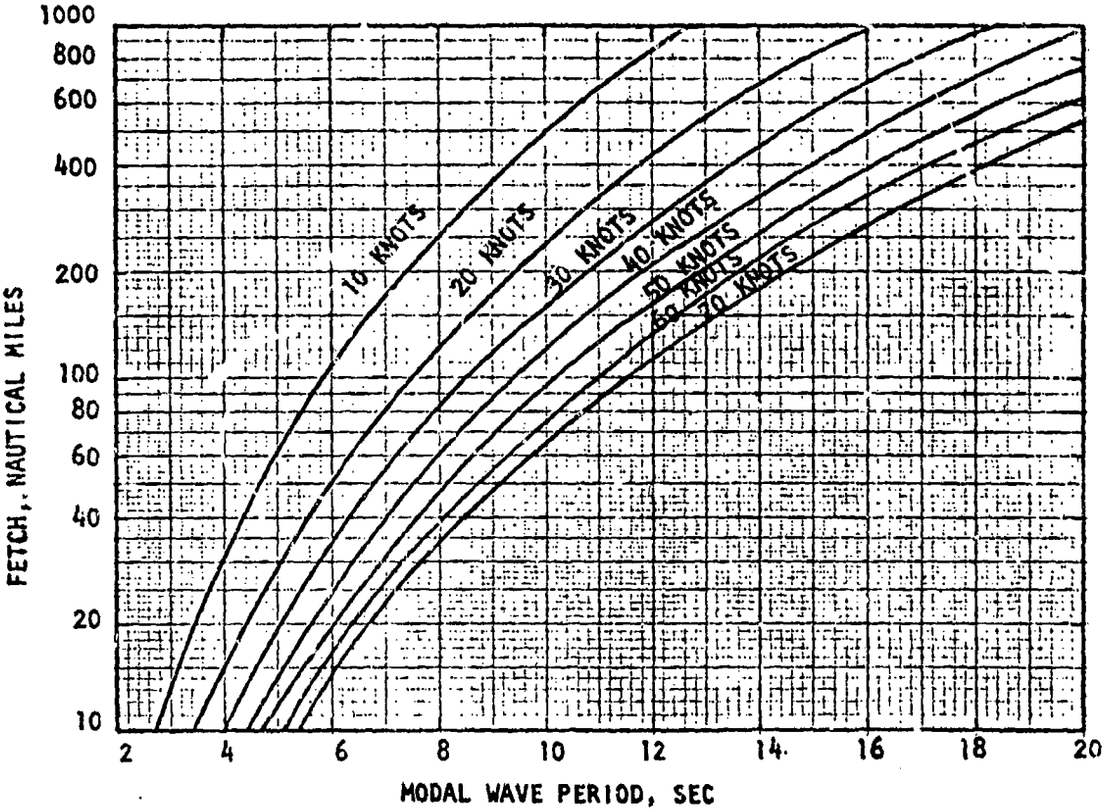


Figure 21 - Modified JONSWAP Spectral Relationships Between Modal Wave Period, Fetch, and Wind Speed (Reference 16)

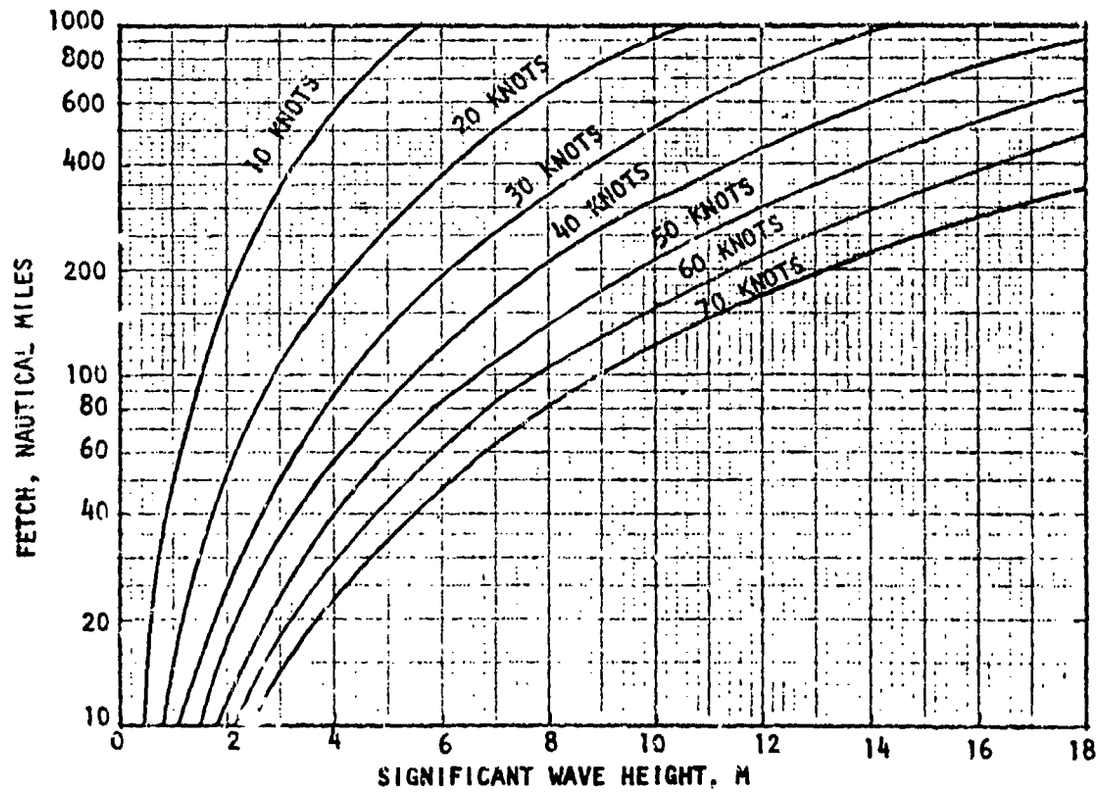


Figure 22 - Modified JONSWAP Spectral Relationships Between Significant Wave Height, Fetch, and Wind Speed (Reference 16)

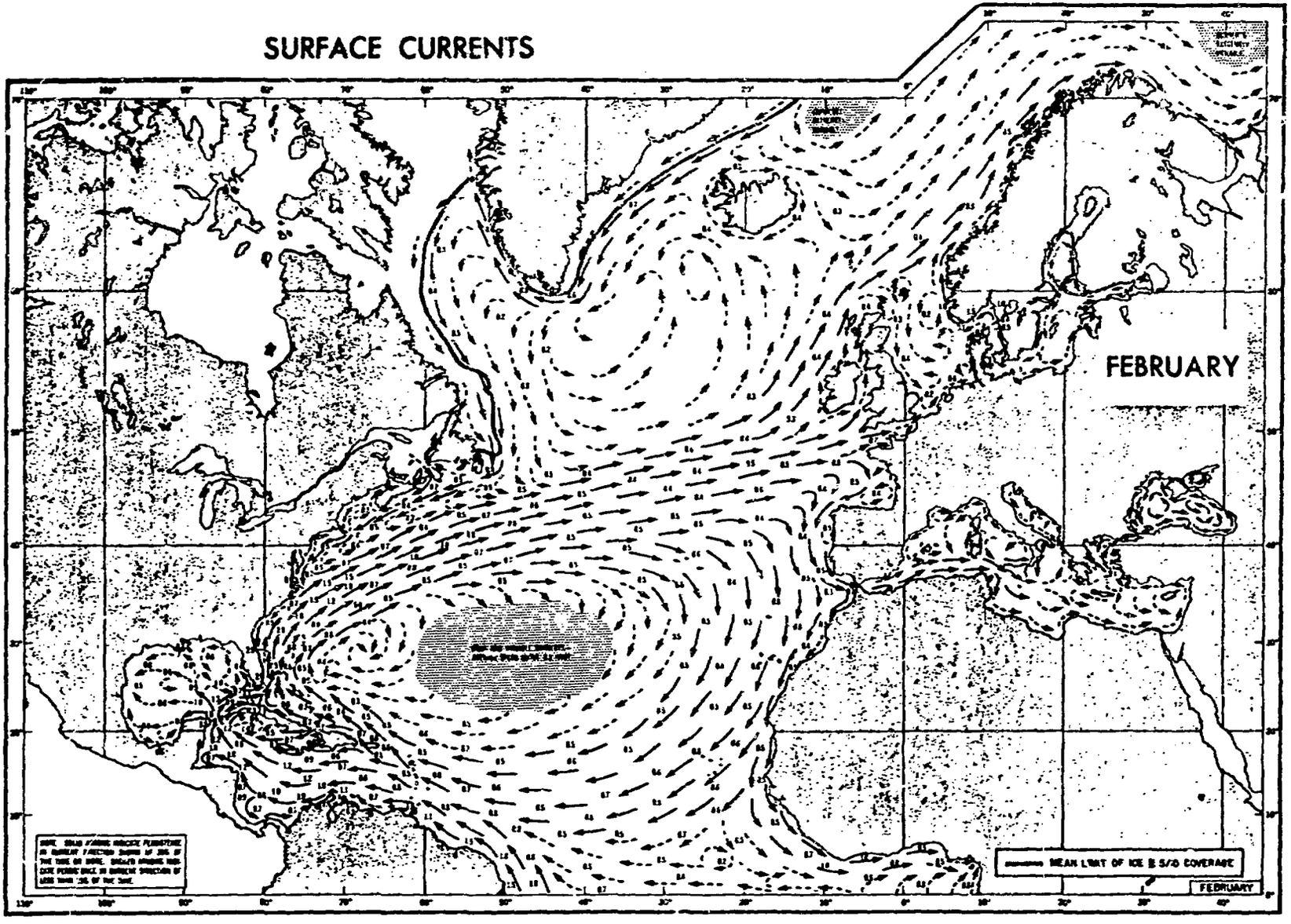


Figure 23 - Generalized Ocean Currents for the NATO Operational Areas for February (Reference 18)

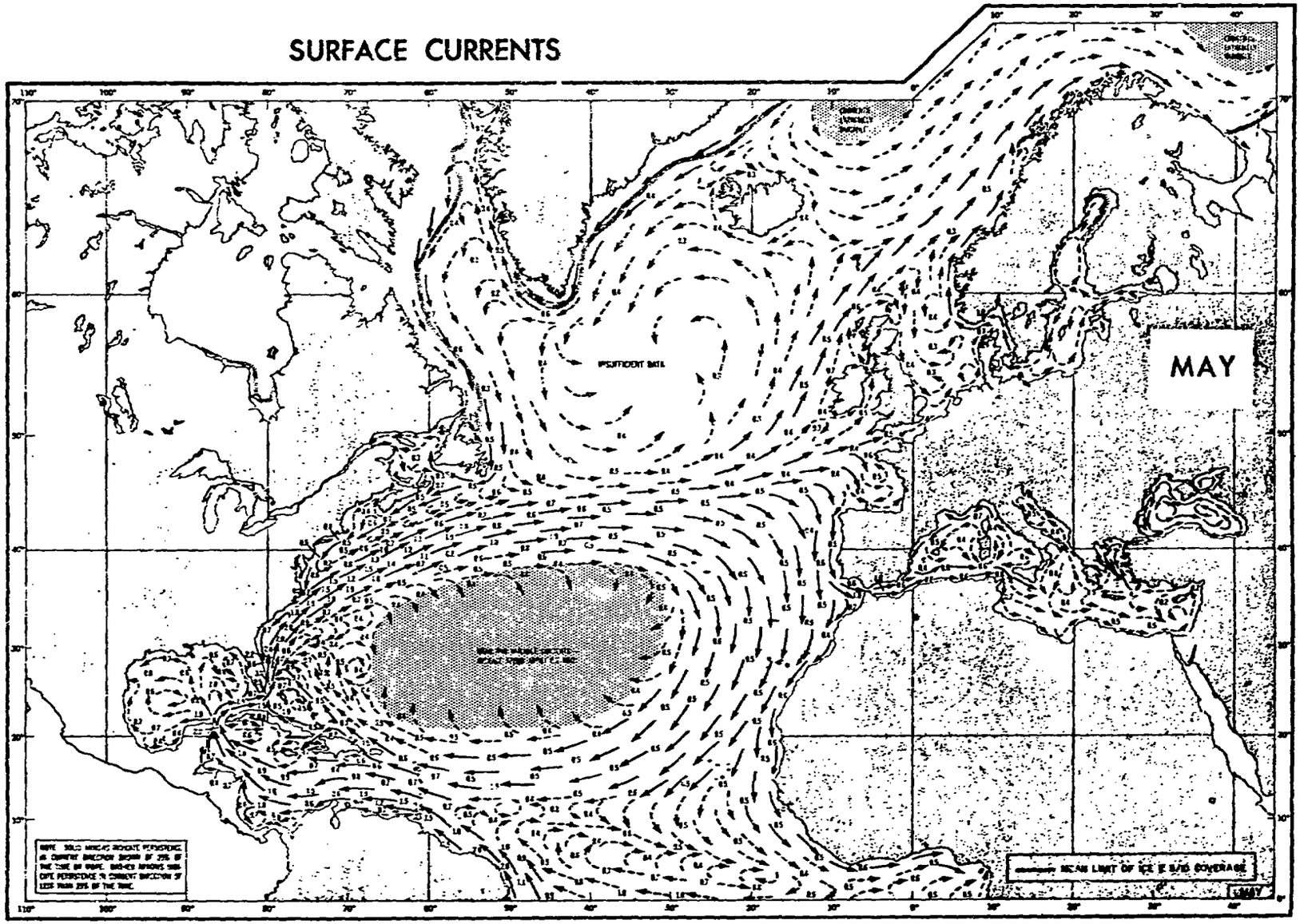


Figure 24 - Generalized Ocean Currents for the NATO Operational Areas for May (Reference 18)

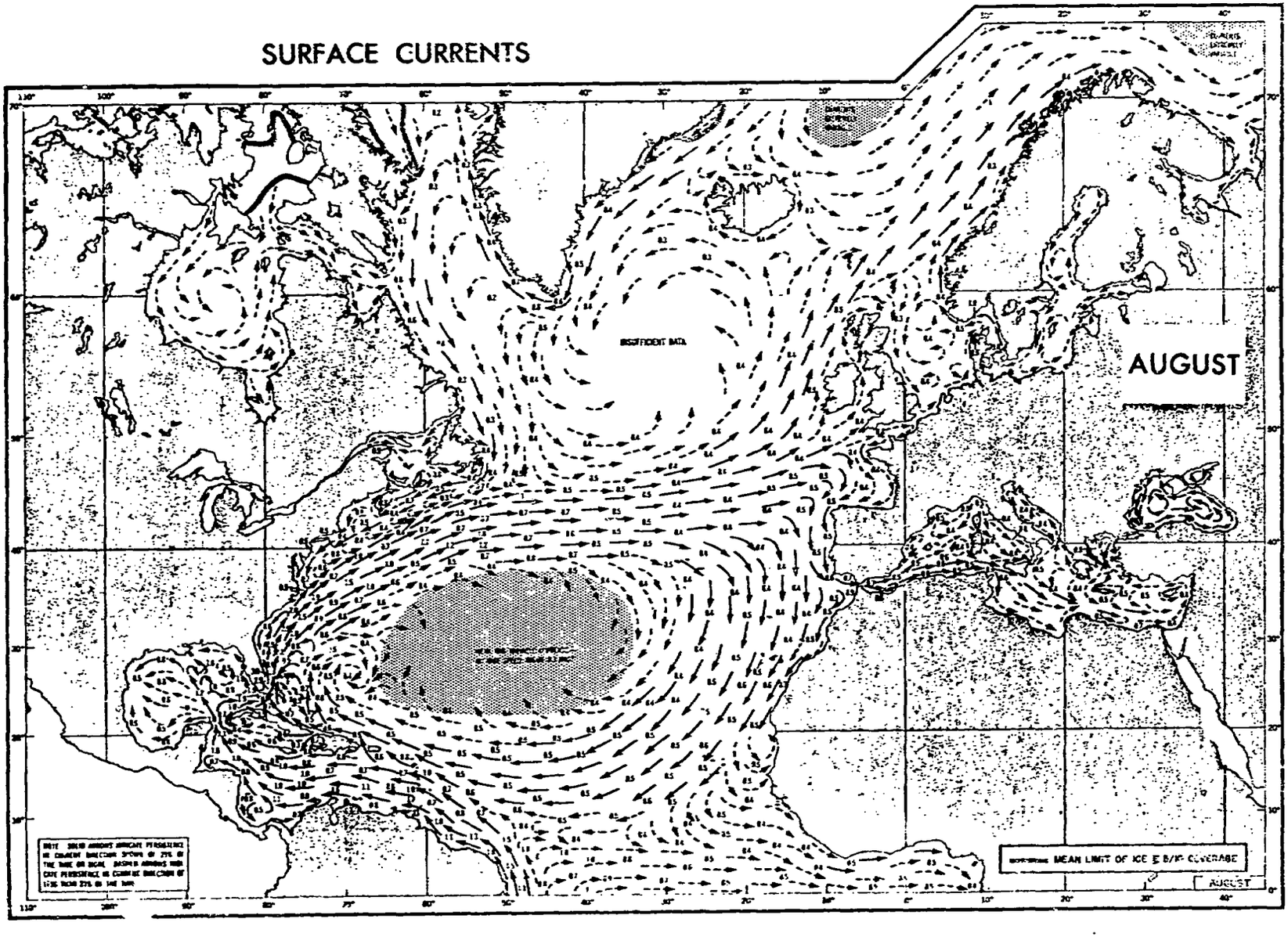


Figure 25 - Generalized Ocean Currents for the NATO Operational Areas for August (Reference 18)

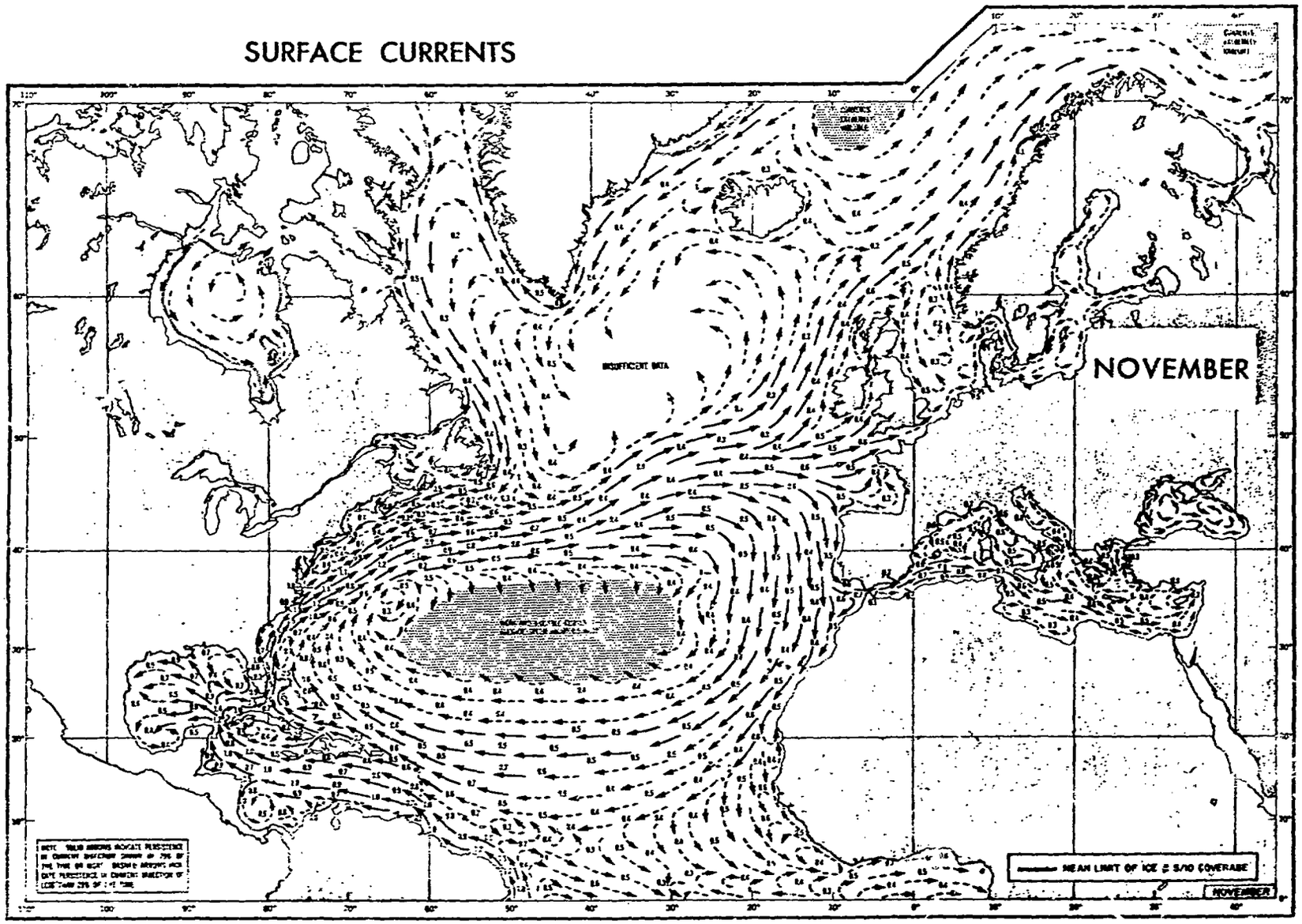


Figure 26 - Generalized Ocean Currents for the NATO Operational Areas for November (Reference 18)

TABLE 1 - TYPICAL HINDCAST DIRECTIONAL SPECTRUM (VARIANCES) (REFERENCE 2)

DATETIME: 9Z 31 MAR 68

LOCATION: 58.292N 12.297W

WIND DIRECTION AND SPEED, WHITECAP PERCENTAGE, FRICTIONAL WIND VELOCITY

WIND DIR 267.6 WIND SPD 22.6 WHITE CPS .0 USTR .31

WAVE FREQUENCY	FREQ	.308	.208	.158	.133	.117	.103	.092	.081	.072	.067	.061	.056	.050	.044	.039		DIR (FROM)
VARIANCE ENERGY		.0	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.1	6.58
		.0	.1	.2	.2	.2	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.7	336.58
		.1	.2	.3	.3	.3	.2	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.3	306.58
		.1	.2	.4	.4	.6	.4	.3	.0	.0	.0	.0	.0	.0	.0	.0	2.3	276.58
		.1	.2	.3	.3	.4	.1	.2	.1	.0	.0	.0	.0	.0	.0	.0	1.6	246.58
		.0	.1	.2	.1	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.7	216.58
POINT SPECTRUM		.2	.8	1.3	1.2	1.6	.8	.5	.2	.1	.0	.0	.0	.0	.0	.0	6.7	WAVE DIRECTIONS

TOTAL ENERGY

H1/3 10.35 FT (3.2 M)

SIGNIFICANT WAVE HEIGHT

TABLE 2 - LOCATIONS DEFINING NORTH ATLANTIC OCEAN AREAS IN CURRENT STUDY

NATO Area	Subprojection/GP	Latitude (° N)	Longitude (° W)
00	3/110	60.696	33.123
0	3/84	62.851	3.916
1	3/169	52.755	33.765
2	3/127	58.292	12.297
4	3/124	55.870	4.391E
6	2/279	46.191	44.891
7	3/216	45.199	21.648
10	2/228	34.097	52.857
11	3/244	39.912	21.794
16	2/224	29.748	66.526
17	2/182	26.694	48.502

TABLE 3 - MODAL WAVE PERIOD VALUES FOR SEAKEEPING PERFORMANCE ASSESSMENTS

f (SOWM) Hertz	T Seconds
.039	25.6
.044	22.7
.050	20.0
.056	17.8
.061	16.4
.067	14.9
.072	13.9
.081	12.3
.092	10.9
.103	9.7
.113	8.8
.117	8.5
.158	6.3
.208	4.9
.308	3.2

TABLE 4 - SAMPLE SPREADING WEIGHTS (α OF 15 DEGREES AND ν OF 0 DEGREES) (REFERENCE 8)

W	ν^*	90	75	60	45	30	15	0
WAVE ANGLES, ν	-90	0.000	–	–	–	–	–	–
	-75	0.011	0.000	–	–	–	–	–
	-60	0.042	0.019	0.000	–	–	–	–
	-45	0.083	0.069	0.037	0.000	–	–	–
	-30	0.125	0.131	0.125	0.083	0.000	–	–
	-15	0.156	0.181	0.213	0.250	0.250	0.000	0.000
	0 (μ)	0.167	0.200	0.250	0.333	0.500	1.000	1.000
	15	0.156	0.181	0.213	0.250	0.250	0.000	0.000
	30	0.125	0.131	0.125	0.083	0.000	–	–
	45	0.083	0.069	0.037	0.000	–	–	–
	60	0.042	0.019	0.000	–	–	–	–
	75	0.011	0.000	–	–	–	–	–
	90	0.000	–	–	–	–	–	–

TABLE 5 - NATURAL ENVIRONMENT VERSUS SHIP FUNCTION

	Mobility	Detection and Communication Systems (Radar, Sonar, Helo, etc.)	Defense (Weapons)	Ship Tactics*
Sea Surface Wave height, period, direction (currents)	x	x	x	x
Surface Winds Wind speed, direction	x	x	x	x
Visibility		x	x	x
Cloud Cover		x	x	x
Ceiling Height		x		x
Precipitation		x	x	x
Fog		x	x	x
Humidity		x	x	x
Temperature		x		x
Sea Level Pressure		x		x
Storm	x	x	x	x
Ice Concentration	x			x
Superstructure Icing	x	x	x	x
Refractivity Profile		x		x
Ducting		x		x
Ionispheric Data		x		x

*Nominally, ship tactical decisions can be influenced by any environmental parameter which impacts any ship function.

APPENDIX A
SEASONAL CLIMATOLOGY OF THE NORTH ATLANTIC OCEAN

The following data graphs are derived primarily from the Ten Year Hindcast Climatology, see Reference 2. Tables A-(0,00,1,2,4,6,7,10,11,16,17)-1-1 are developed from Reference 9.

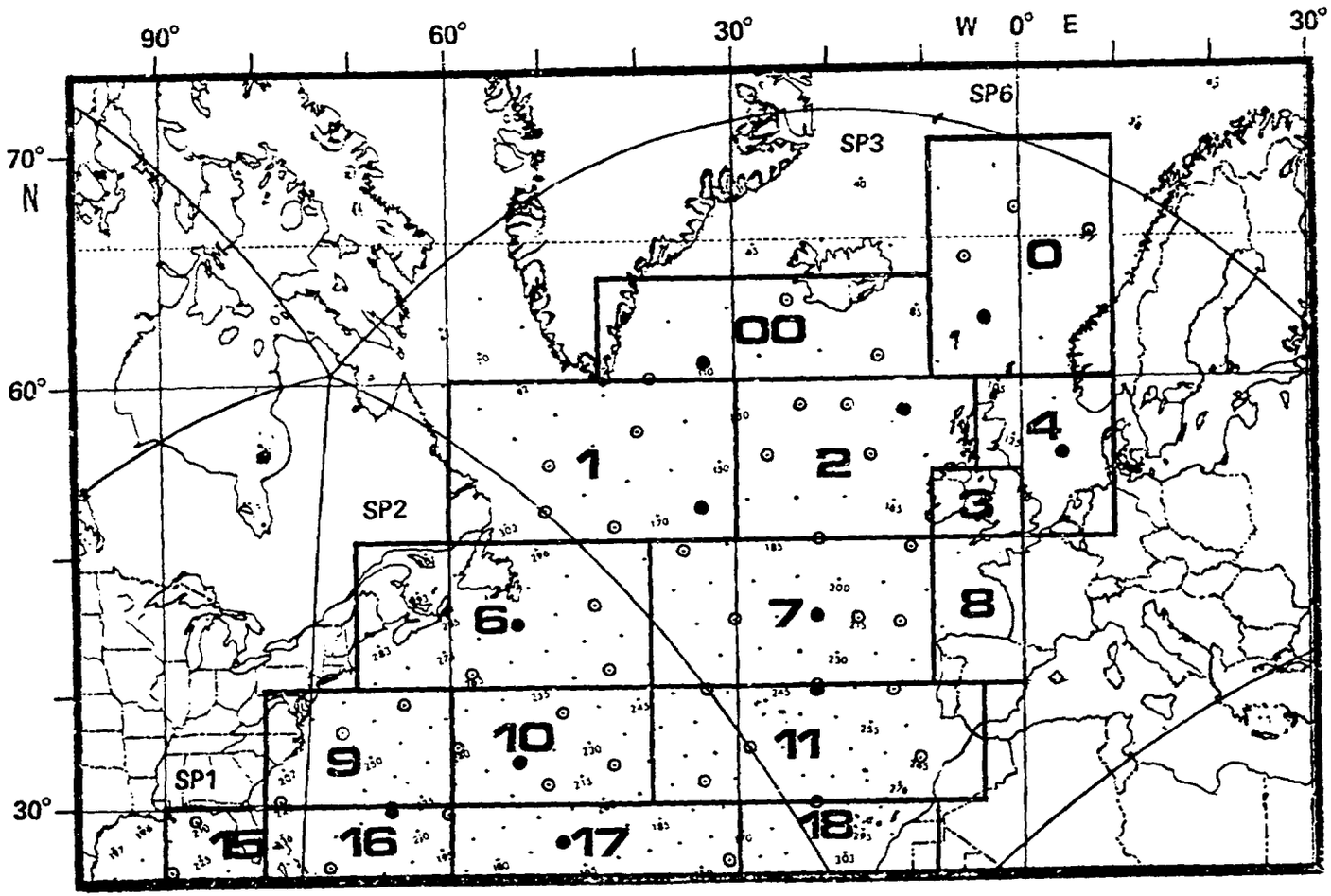


Figure A-1- Selection of Representative Areas in the North Atlantic Basin

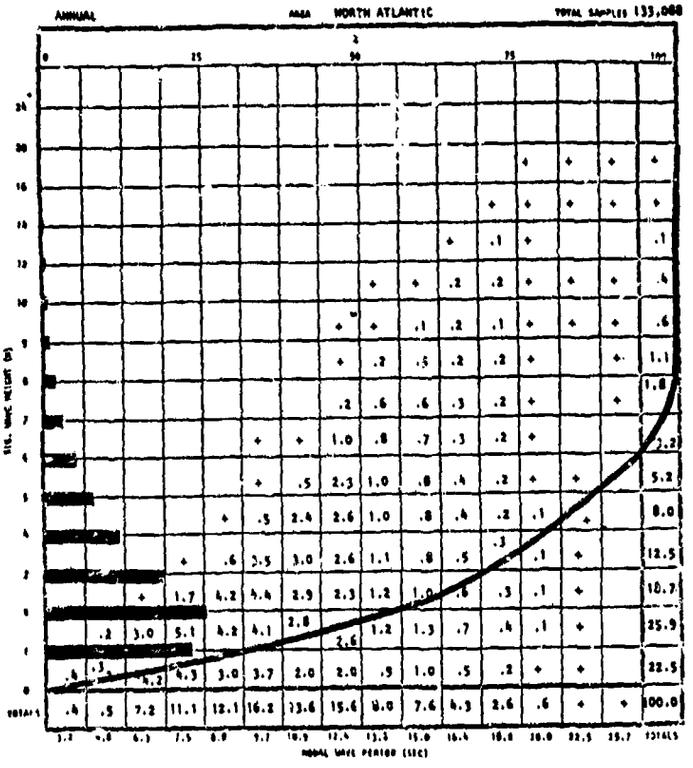


Figure A-2 Significant Wave Height
by Modal Wave Period

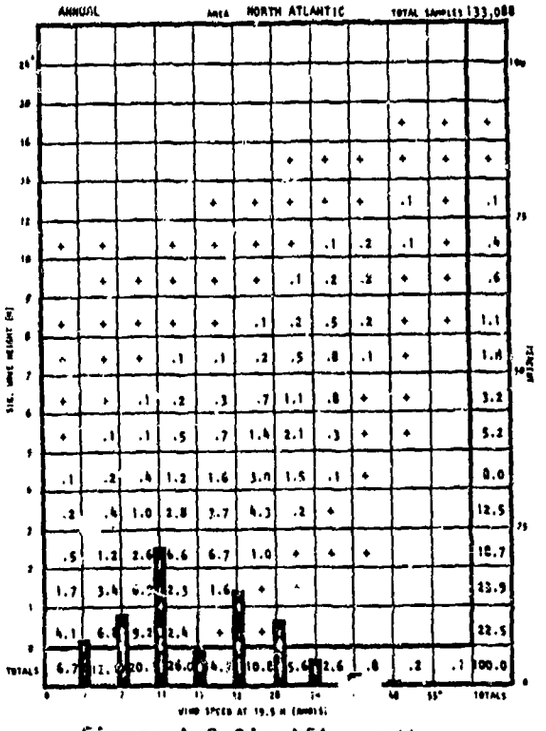


Figure A-3 Significant Wave
Height by Wind Speed

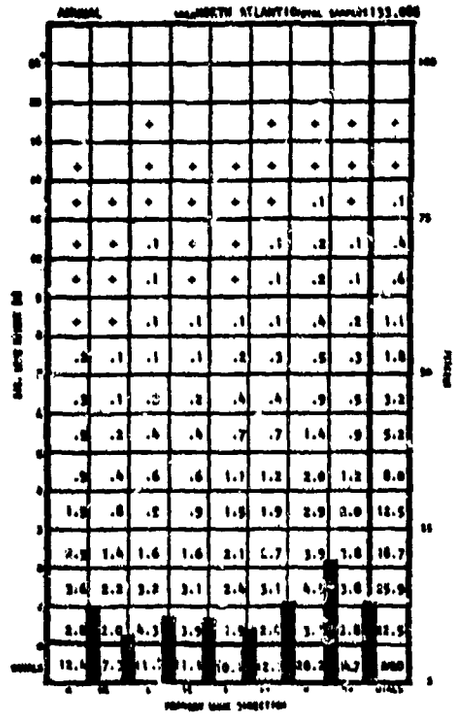


Figure A-4 Significant Wave Height by Wave Direction

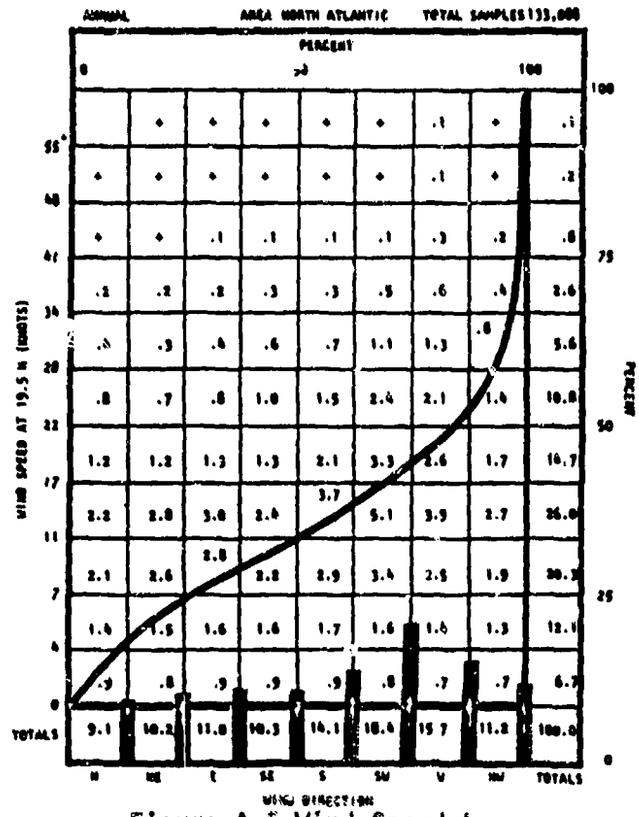


Figure A-5 Wind Speed by Wind Direction

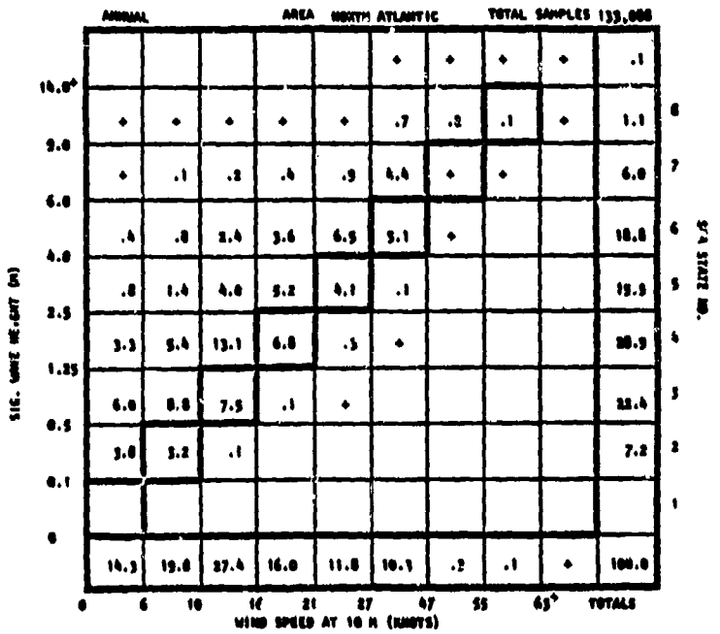


Figure A-6 Significant Wave Height by Wind Speed (WMO Sea State Chart)

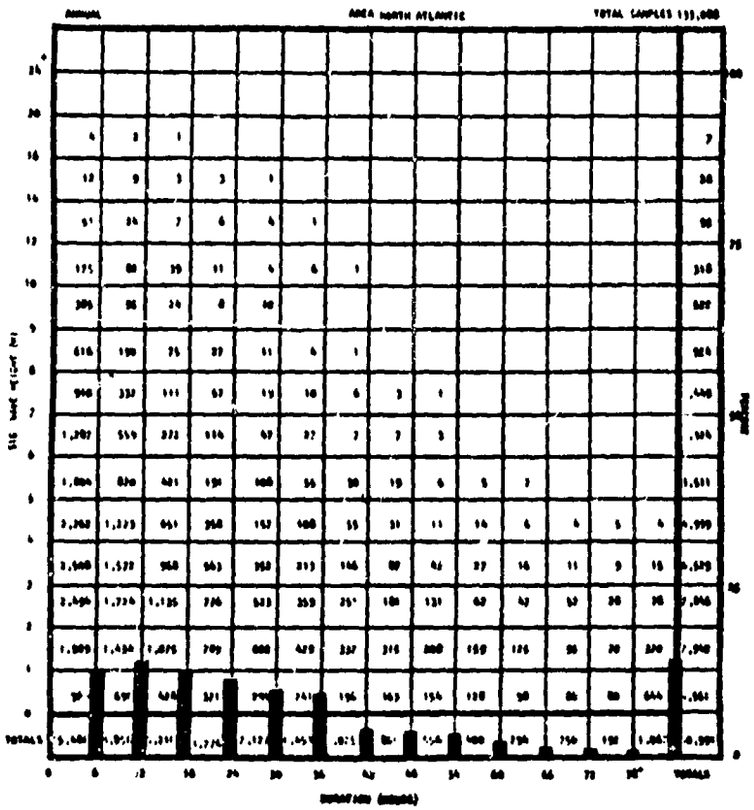


Figure A-7 Persistence of Significant Wave Height

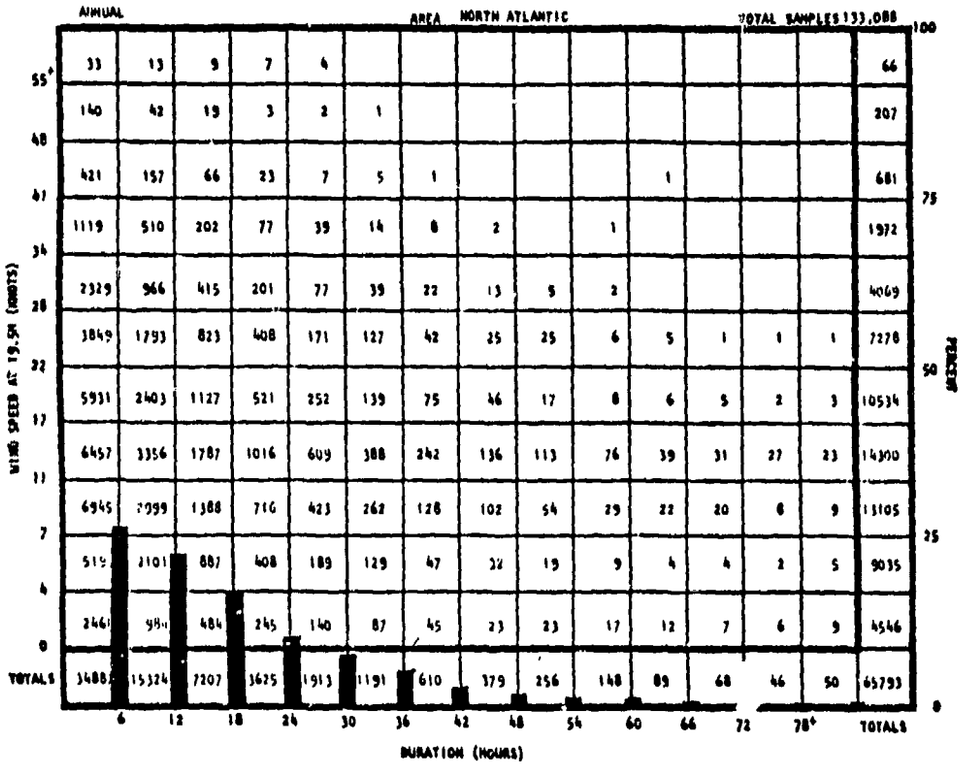


Figure A-8 Persistence of
Wind Speed

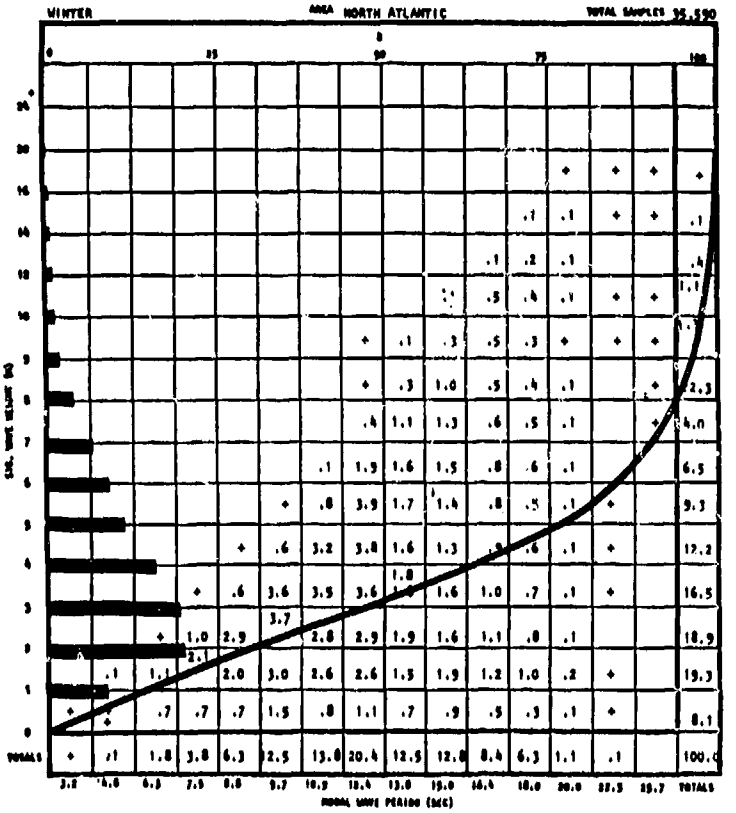


Figure A-9 Significant Wave Height
by Modal Wave Period

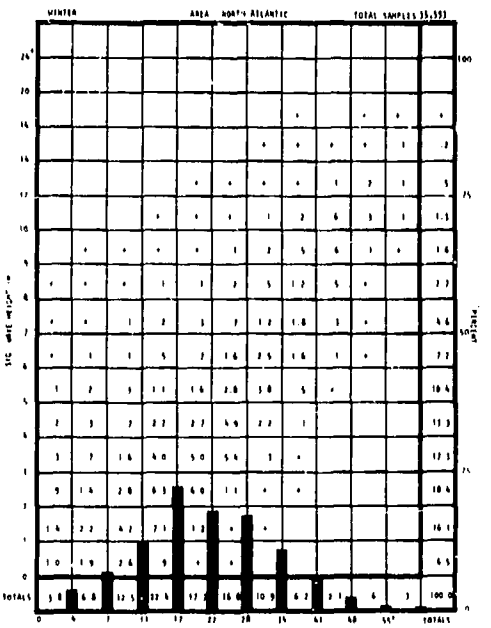


Figure A-10 Significant Wave
Height by Wind Speed

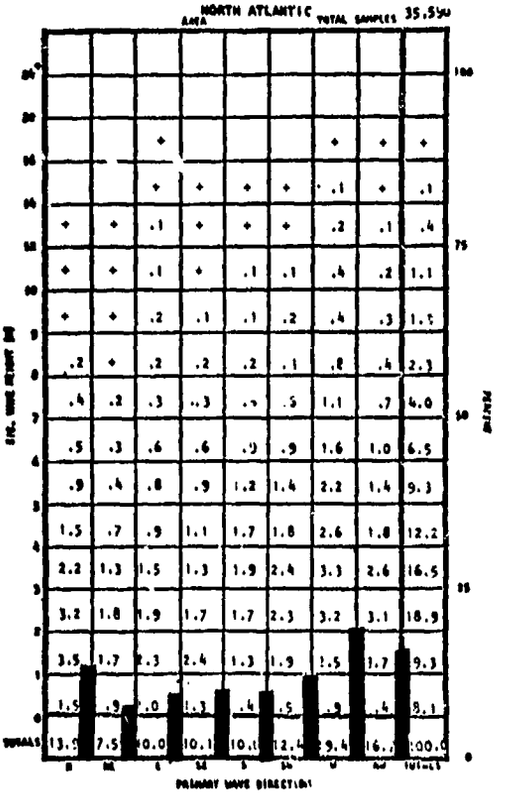


Figure A-11 Significant Wave Height by Wave Direction

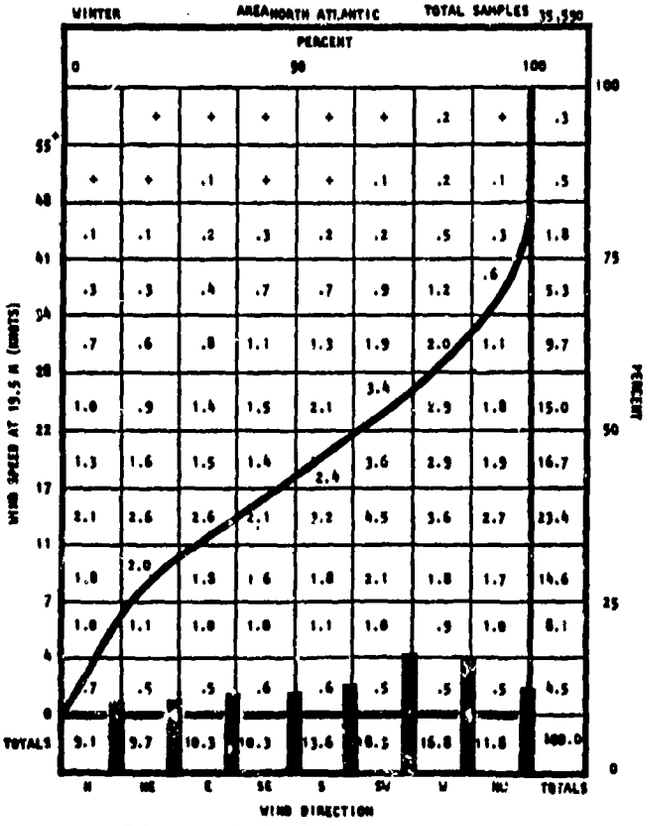


Figure A-12 Wind Speed by Wind Direction

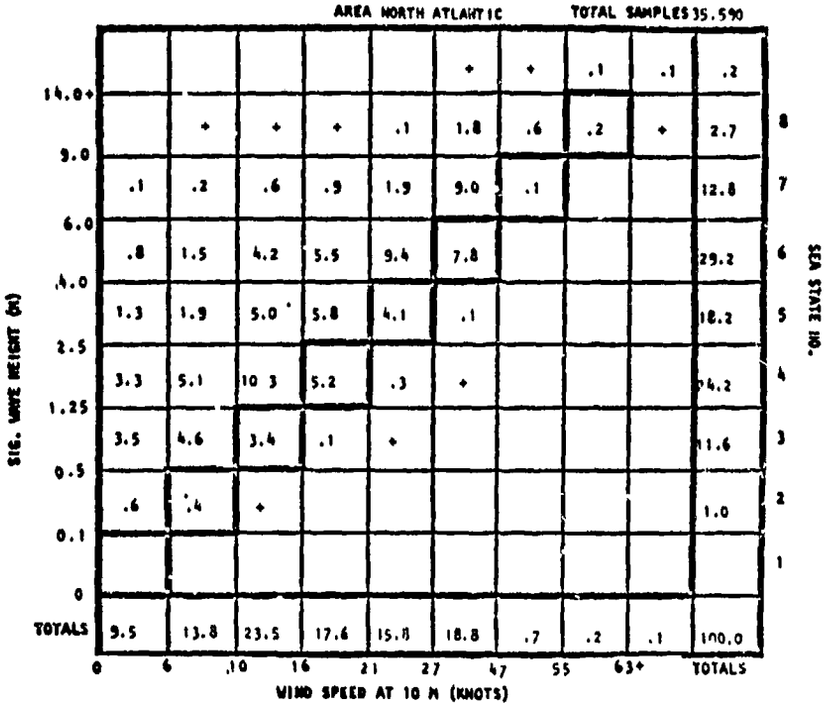


Figure A-13 Significant Wave Height by Wind Speed (WMO Sea State Chart)

TABLE A-0-1-1 - SURFACE NATURAL ENVIRONMENT SUMMARY

Season: Annual; Location: 62.851° N, 3.916° W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface Sig. Wave Height, m. Wave Period, sec Direction	.5 6 -	3 10 -	7 16.5 -	3 11.5 -	2 9.5 SW - W - N
Winds Speed, knots Corresponding Mean Sig. Wave Height, m. Direction	4 1 -	15 2.5 -	33 6.5 -	16 2.5 -	14 2.5 S - SW
Visibility, nautical miles	2	10	25	-	-
Cloud Cover Total clouds, in eighths of sky obscured Low clouds, in eighths of sky obscured	1 1	7 6	8 8	- -	- -
Precipitation (Occurrence)	All precipitation - 22% of the time		Snow - 9% of the time (Dec - Mar)		
Relative Humidity, %	64	84	97	-	-
Air Temperature, °C	3.5	8	12.5	8	-
Surface Water Temperature, °C	6.5	9	12	-	-
Sea Level Pressure, millibars	993	1,008	1,028	-	-
Ice	None				
Refractivity Mean Surface Refractivity Sub-Refraction (1 km, Annual) Super-Refraction or Ducting (1 km, Annual)	- - -	- - -	- - -	319 - -	- 1% of the time None

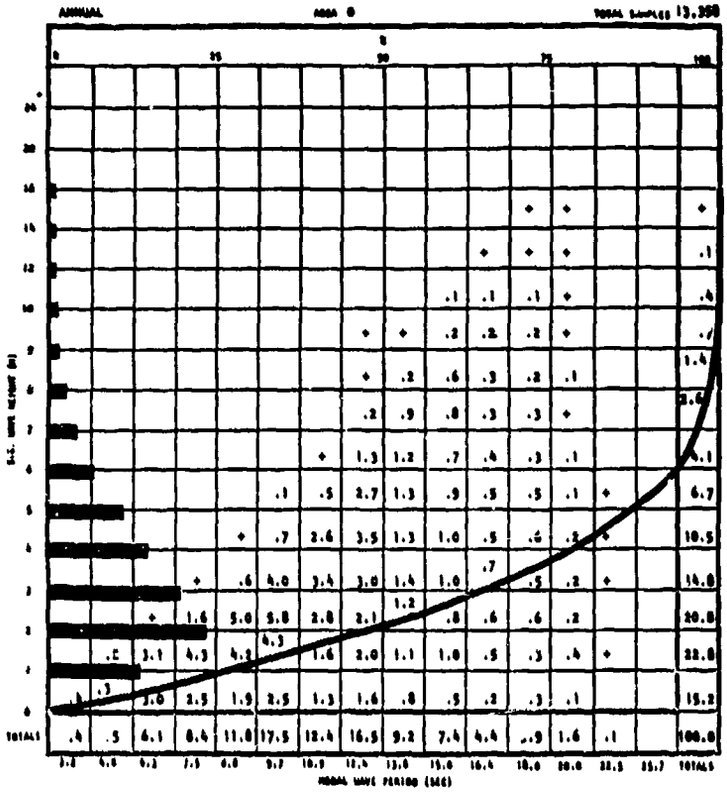


Figure A-0-1-1 Significant Wave Height by Modal Wave Period

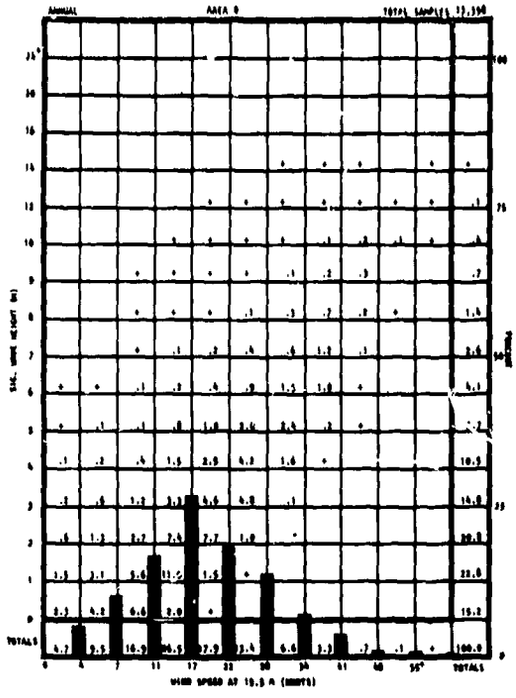


Figure A-0-1-2 Significant Wave Height by Wind Speed

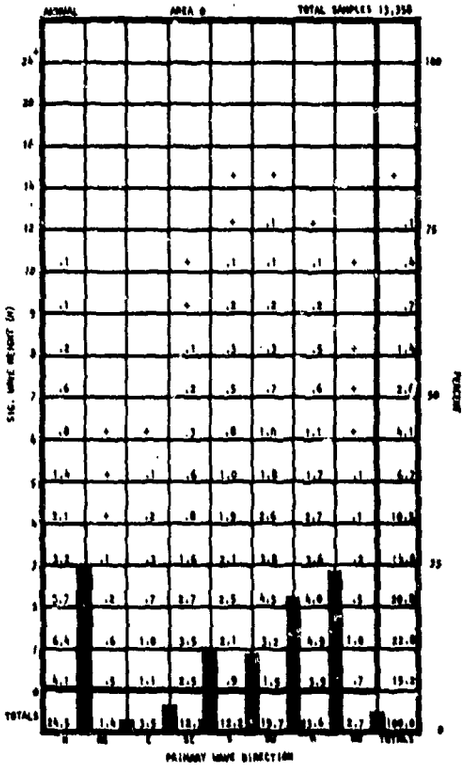


Figure A-0-1-3 Significant Wave Height by Wave Direction

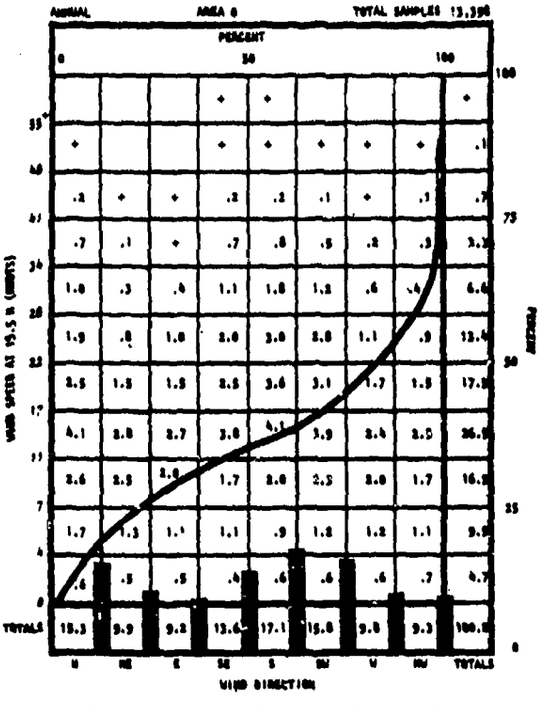


Figure A-0-1-4 Wind Speed by Wind Direction

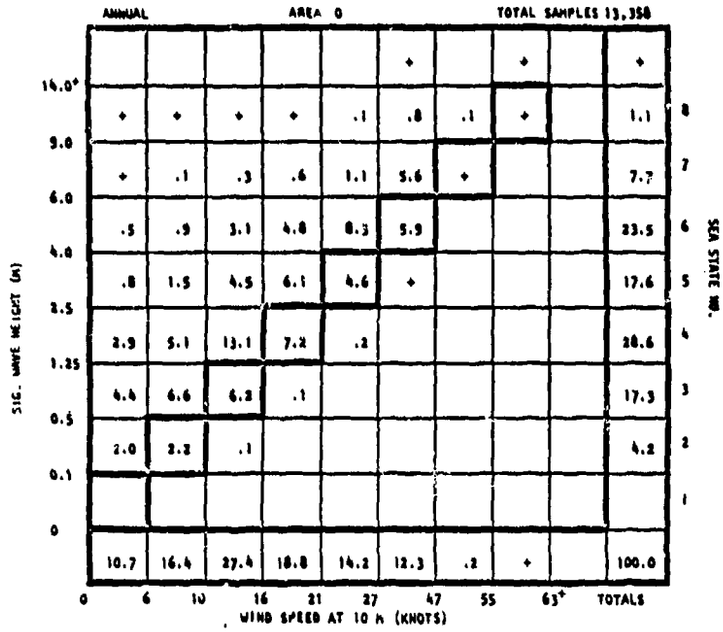


Figure A-0-1-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

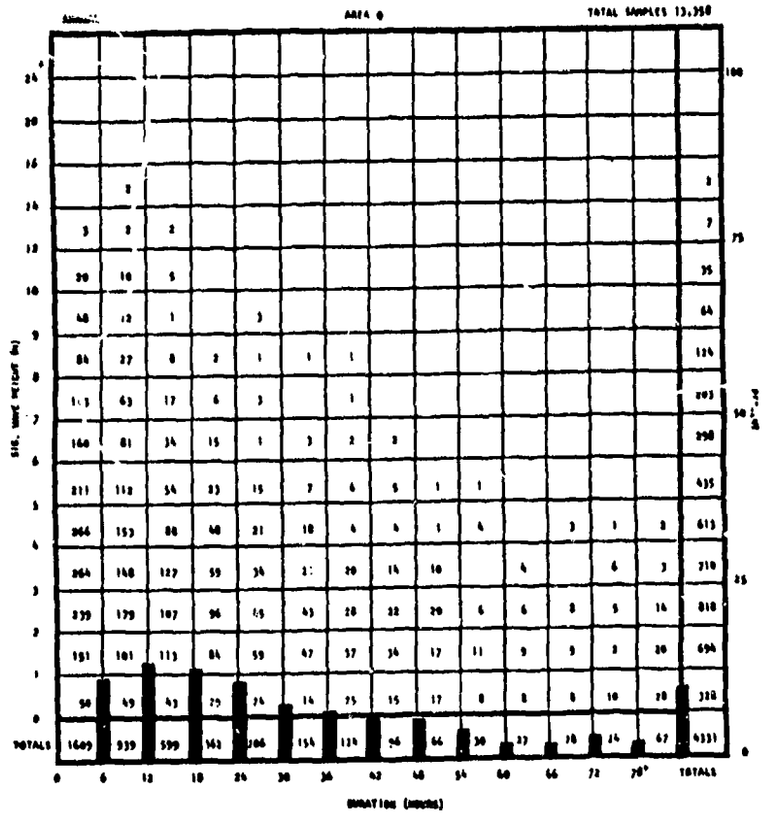


Figure A-0-1-6 Persistence of Significant Wave Height

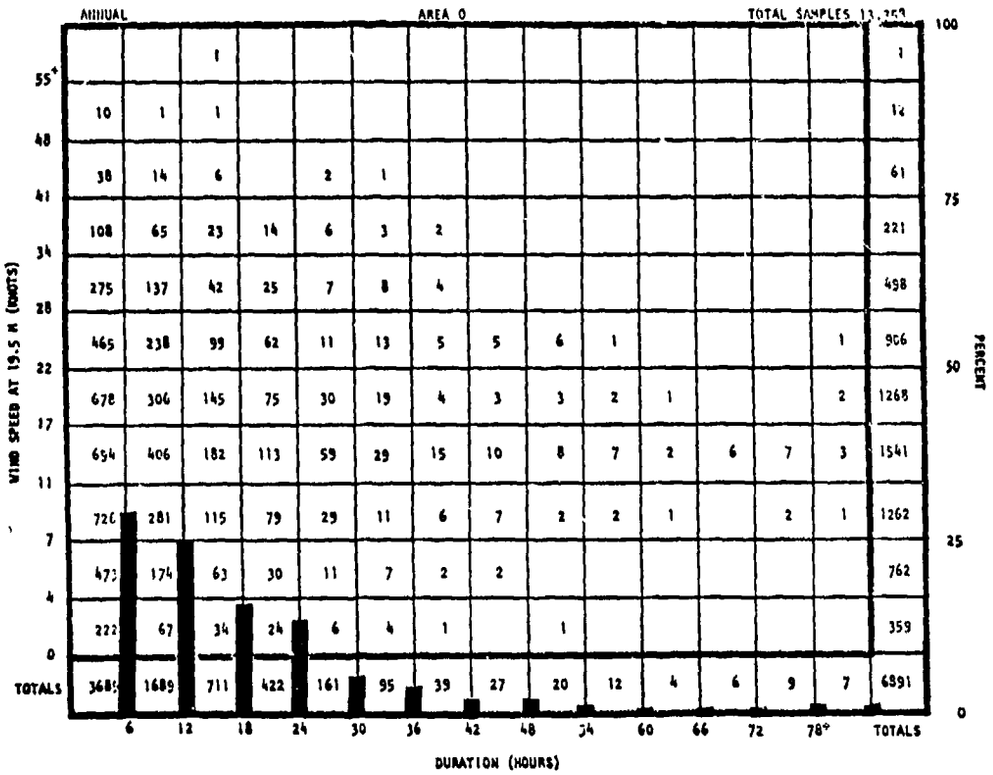


Figure A-0-1-7 Persistence of Wind Speed

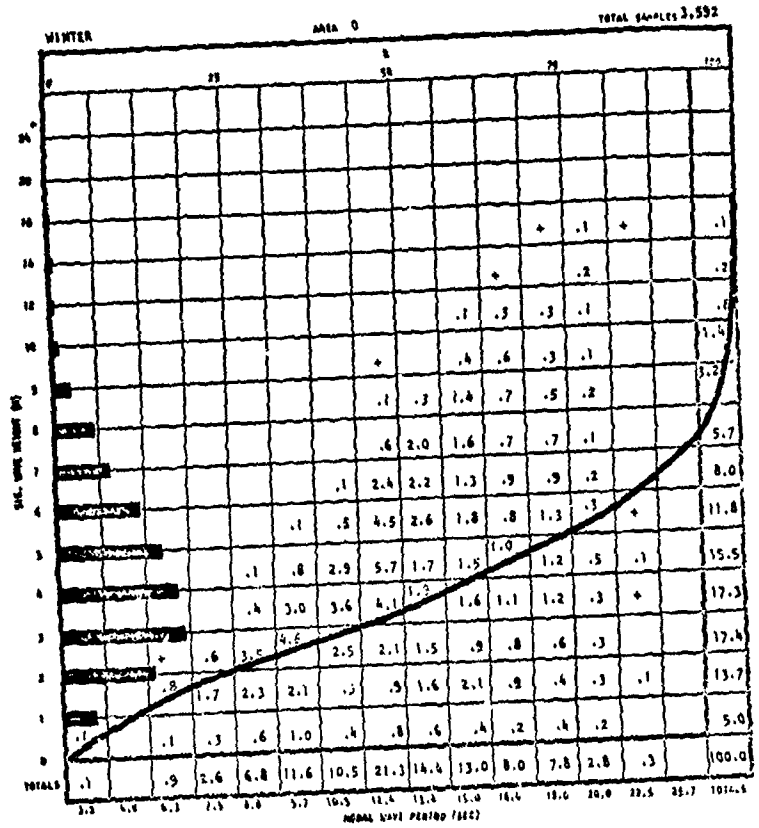


Figure A-0-2-1 Significant Wave Height by Modal Wave Period

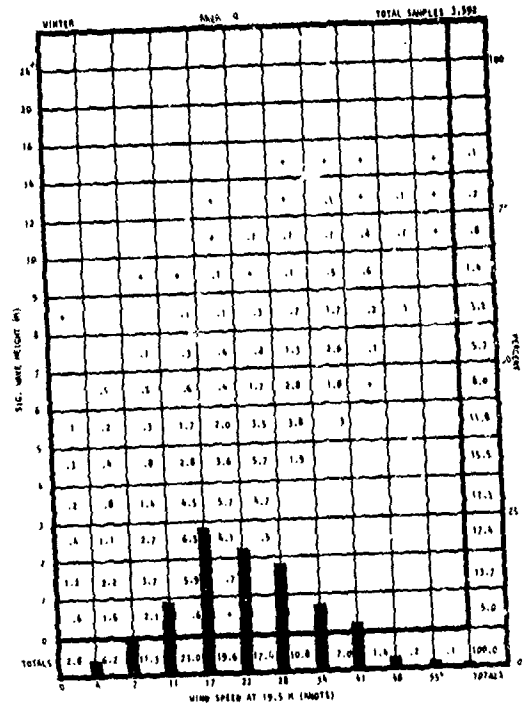


Figure A-0-2-2 Significant Wave Height by Wind Speed

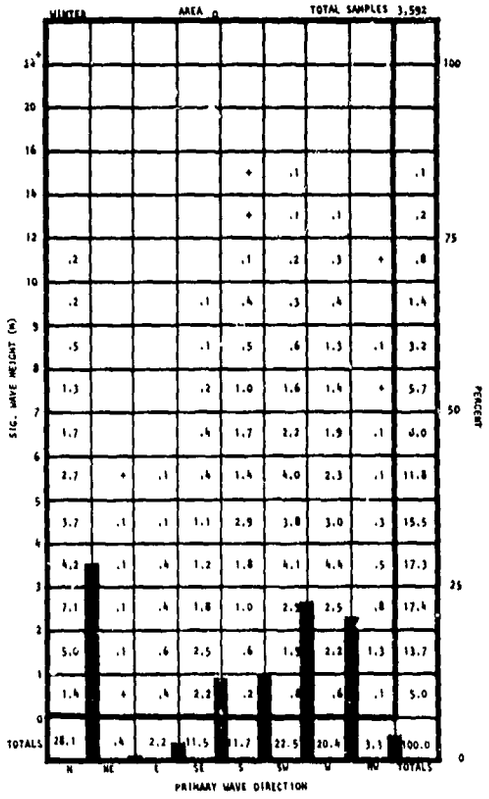


Figure A-0-2-3 Significant Wave Height by Wave Direction

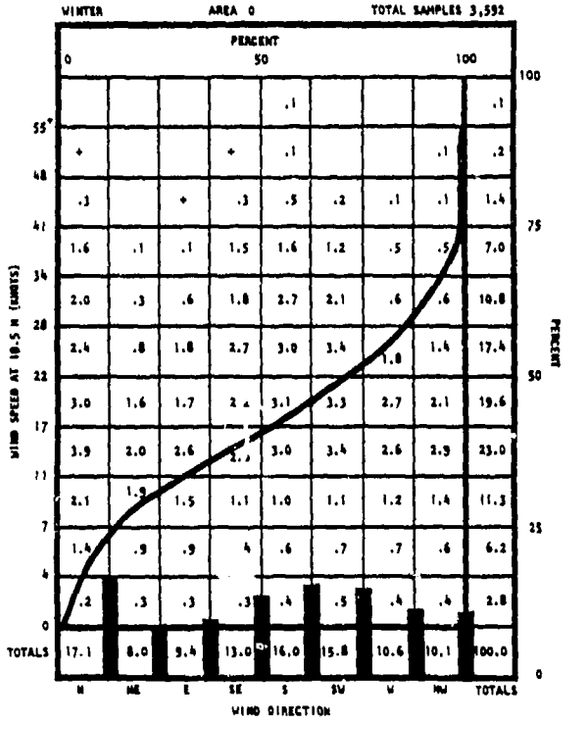


Figure A-0-2-4 Wind Speed by Wind Direction

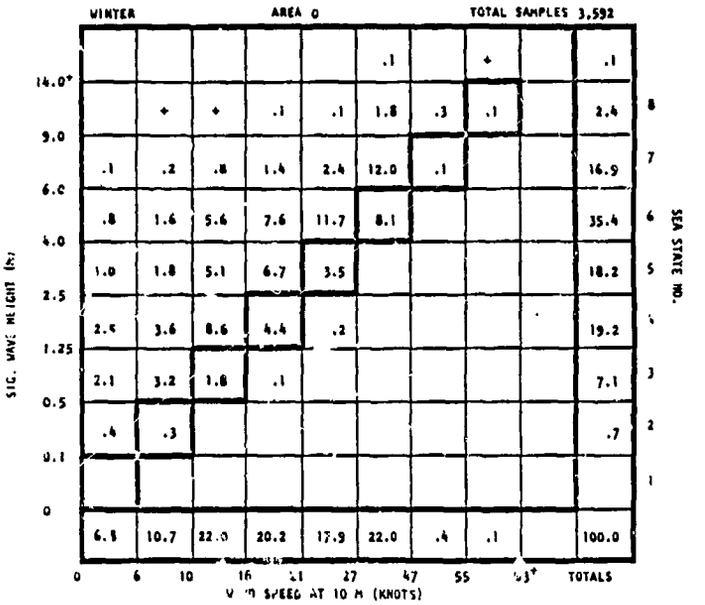


Figure A-0-2-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

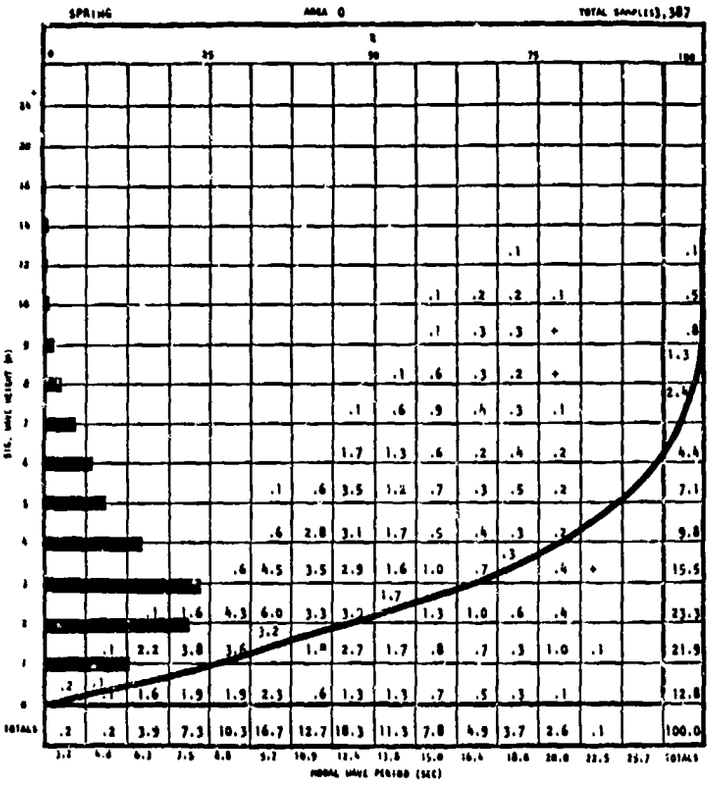


Figure A-0-3-1 Significant Wave Height by Modal Wave Period

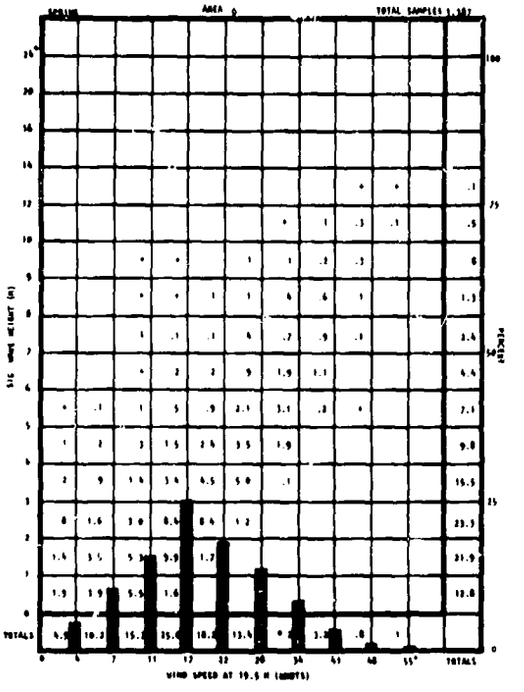


Figure A-0-3-2 Significant Wave Height by Wind Speed

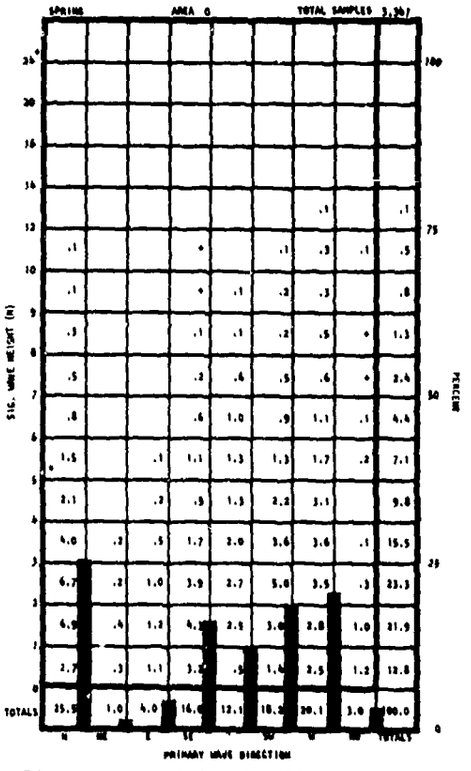


Figure A-0-3-3 Significant Wave Height by Wave Direction

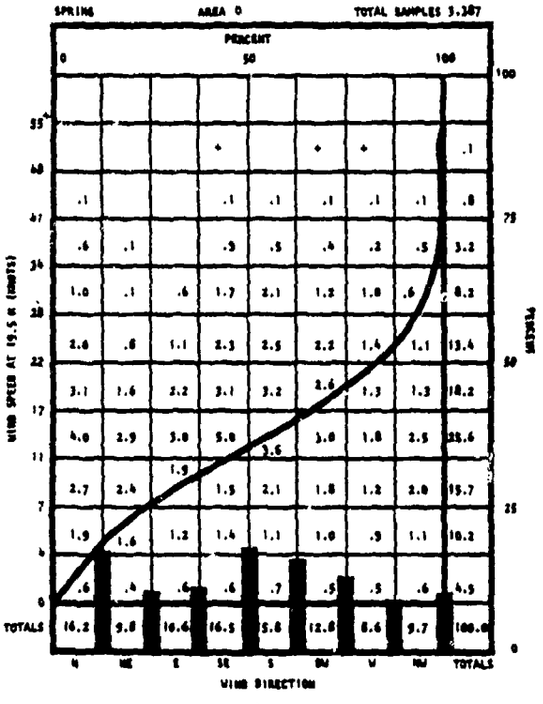


Figure A-0-3-4 Wind Speed by Wind Direction

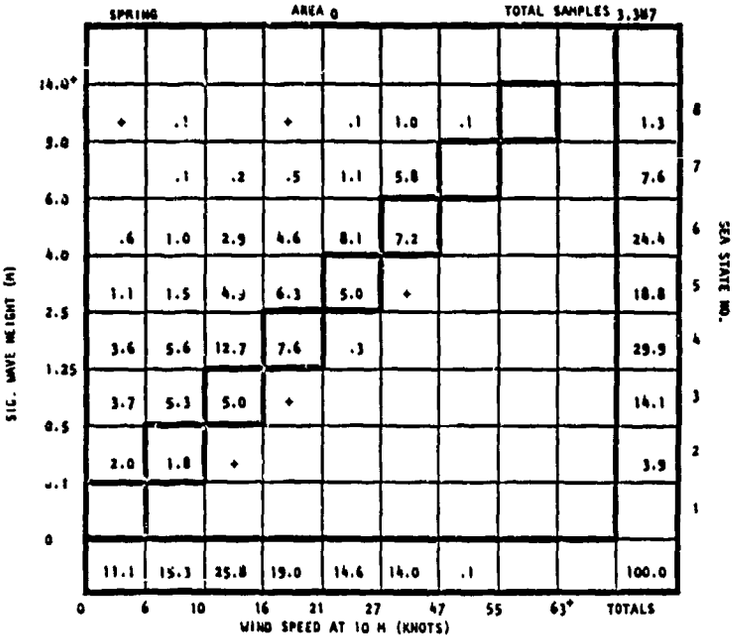


Figure A-0-3-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

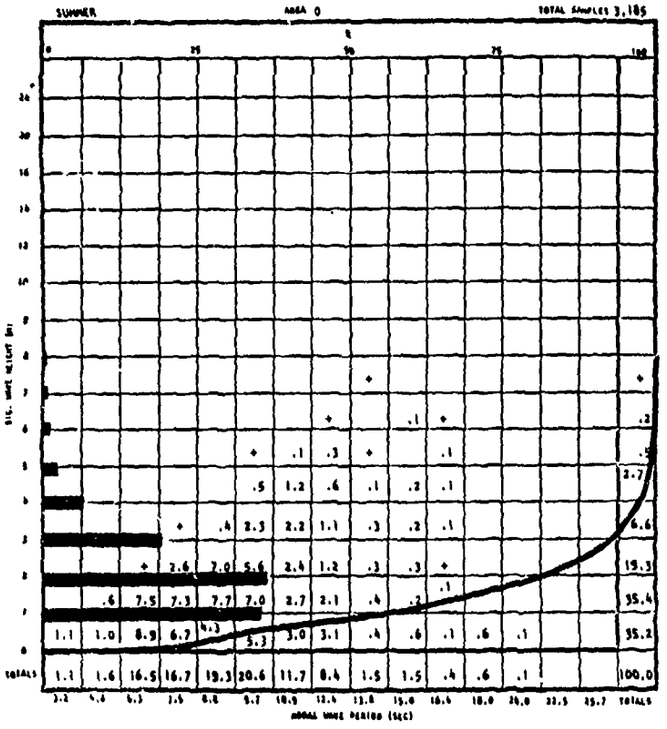


Figure A-0-4-1 Significant Wave Height by Modal Wave Period

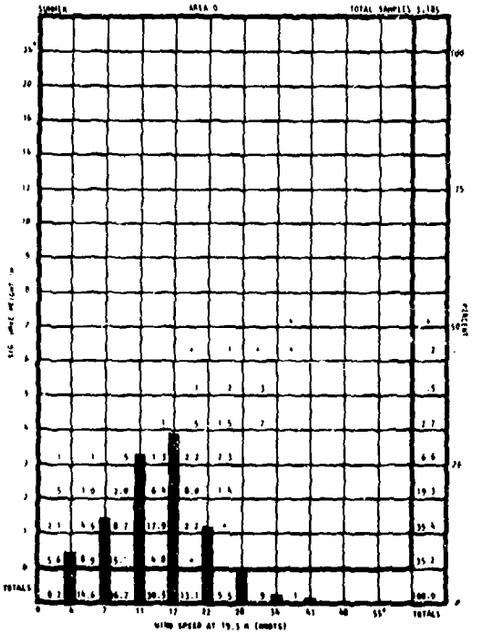


Figure A-0-4-2 Significant Wave Height by Wind Speed

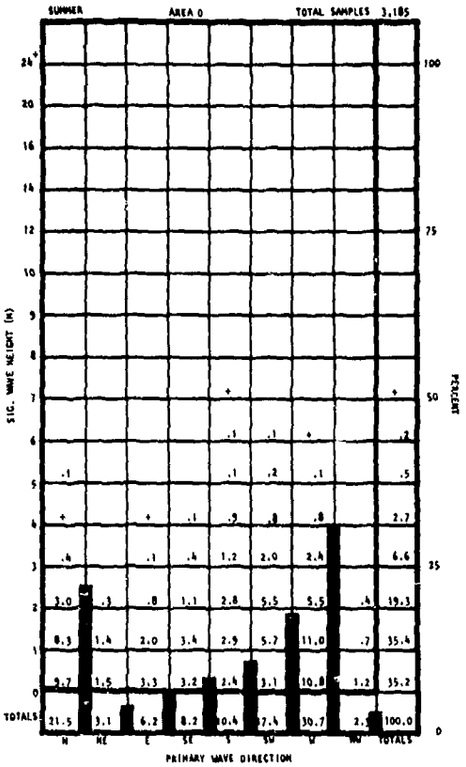


Figure A-0-4-3 Significant Wave Height by Wave Direction

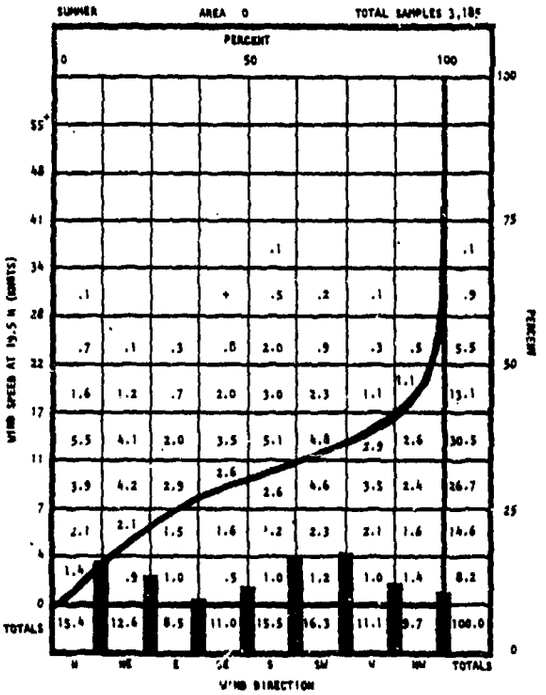


Figure A-0-4-4 Wind Speed by Wind Direction

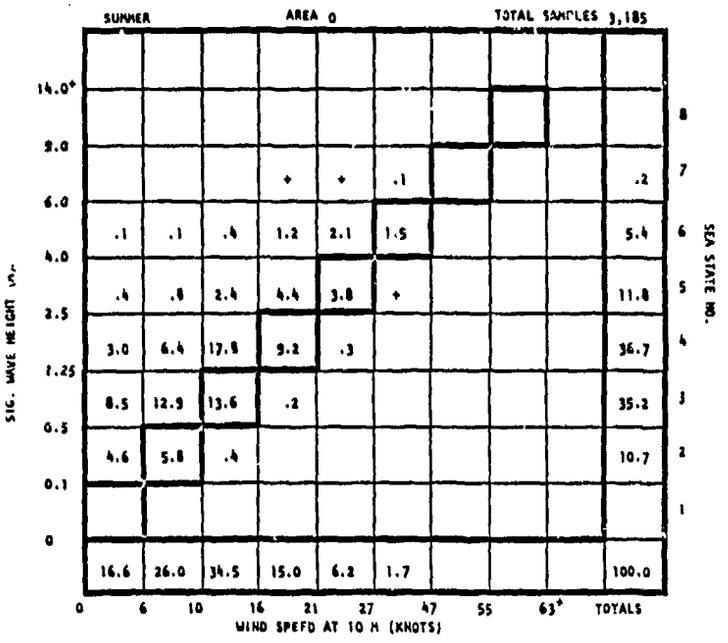


Figure A-0-4-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

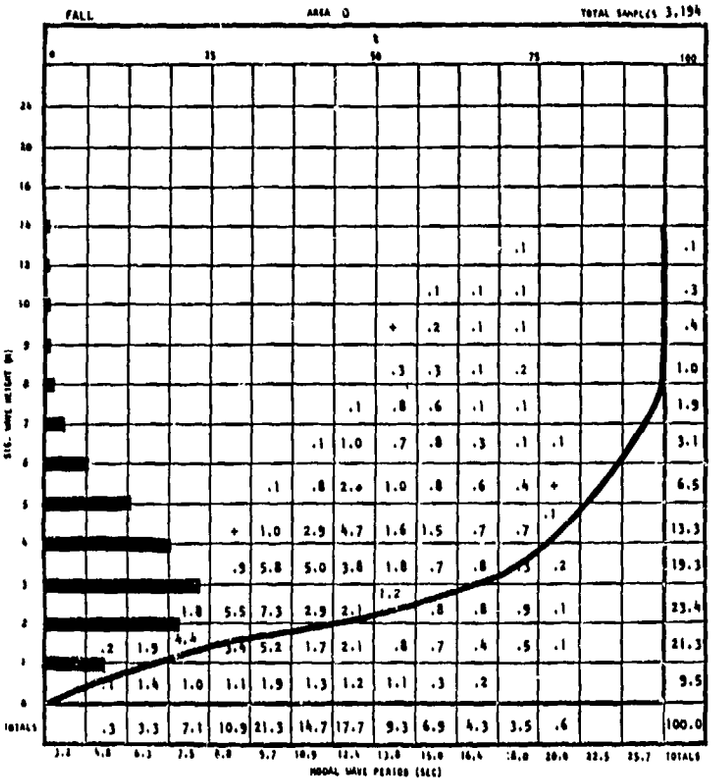


Figure A-0-5-1 Significant Wave Height by Modal Wave Period

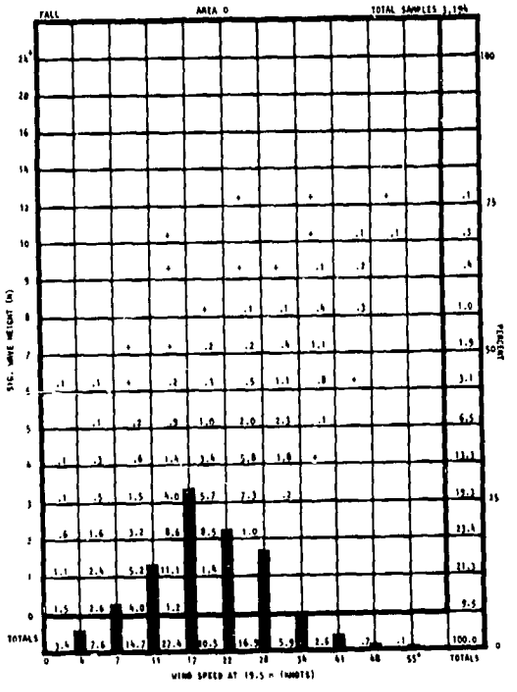


Figure A-0-5-2 Significant Wave Height by Wind Speed

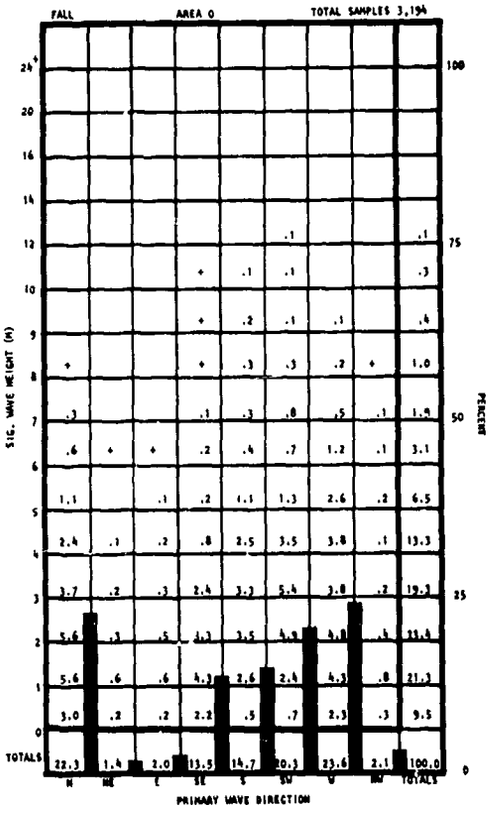


Figure A-0-5-3 Significant Wave Height by Wave Direction

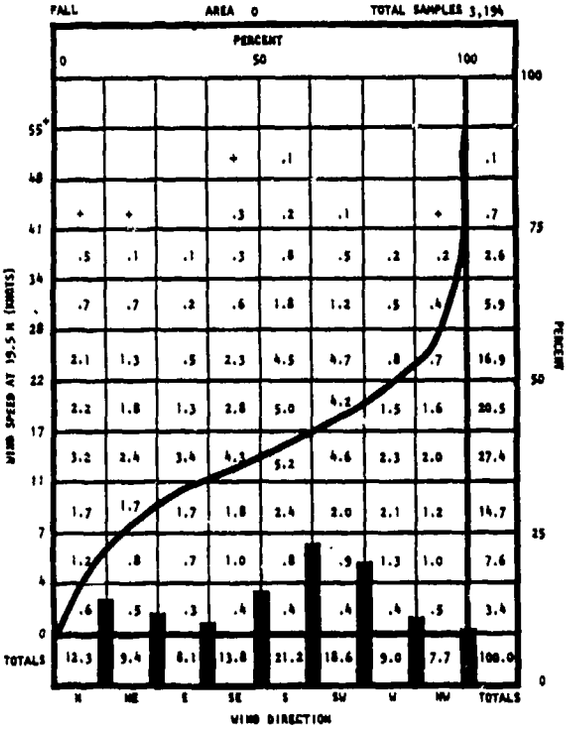


Figure A-0-5-4 Wind Speed by Wind Direction

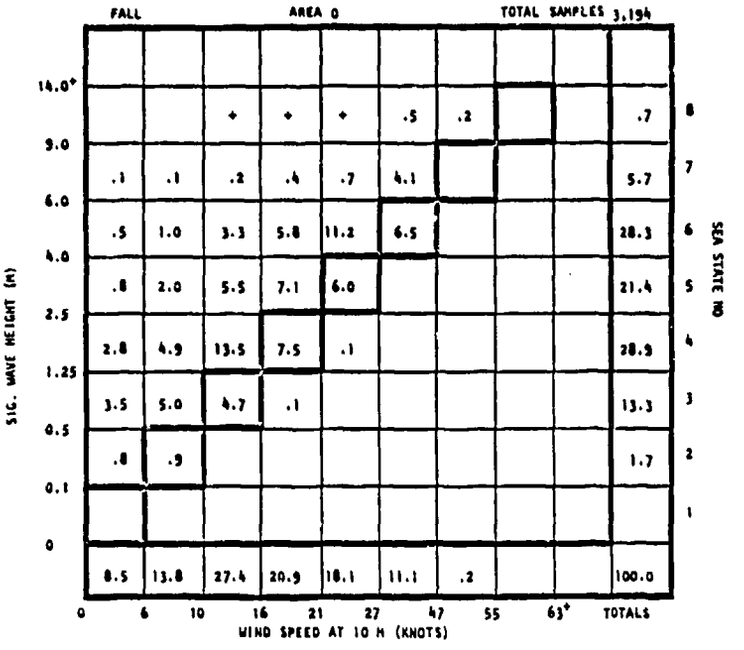


Figure A-0-5-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

TABLE A-00-1-1 - SURFACE NATURAL ENVIRONMENT SUMMARY

Season: Annual; Location: 60.696° N, 33.123° W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface Sig. Wave Height, m. Wave Period, sec Direction	.5 6.5 -	2.5 10 -	7 16 -	3.5 10.5 -	2 9.5 E - S - W
Winds Speed, knots Corresponding Mean Sig. Wave Height, m. Direction	5 1 -	16 2.5 -	35 7 -	18 3 -	14 2.5 NE
Visibility, nautical miles	1.5	10	24	-	-
Cloud Cover Total clouds, in eighths of sky obscured Low clouds, in eighths of sky obscured	1 .5	7 6	8 8	- -	- -
Precipitation (Occurrence)	All precipitation - 25% of the time		Snow - 13% of the time (Dec - Mar)		
Relative Humidity, %	63	83	97	-	-
Air Temperature, °C	.5	5	10	5.5	-
Surface Water Temperature, °C	5	6.5	10.5	-	-
Sea Level Pressure, millibars	981	1,005	1,026	-	-
Ice	Moderate* superstructure icing - 3% of the time (Dec - Mar)				
Refractivity Mean Surface Refractivity Sub-Refraction (1 km, Annual) Super-Refraction or Ducting (1 km, Annual)	- - -	- - -	- - -	316 - -	- None None

*Buildup of less than 1/10 in. per hour (derived from observations with temperature < -2.2°C and wind speed ≥ 13 knots).

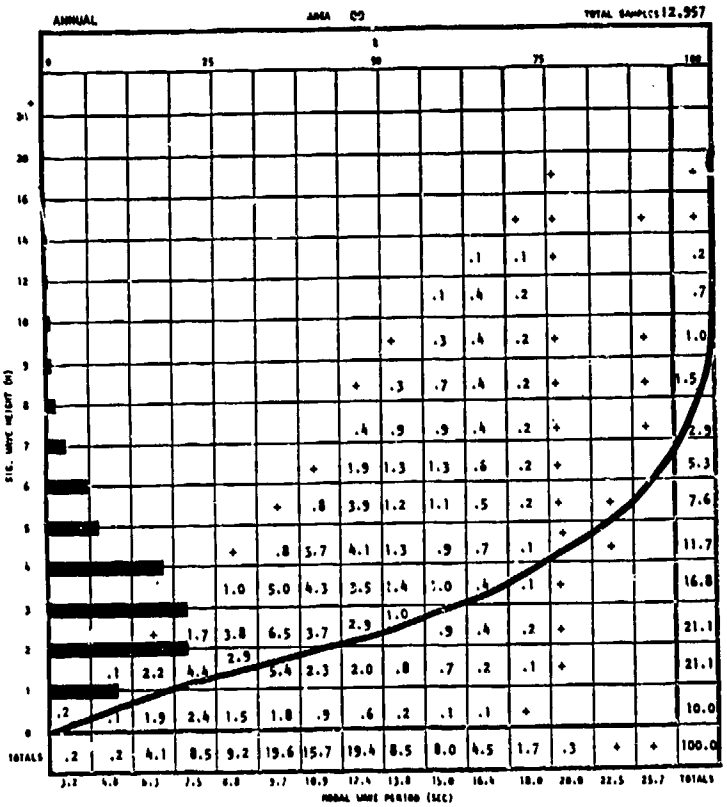


Figure A-00-1-1 Significant Wave Height by Modal Wave Period

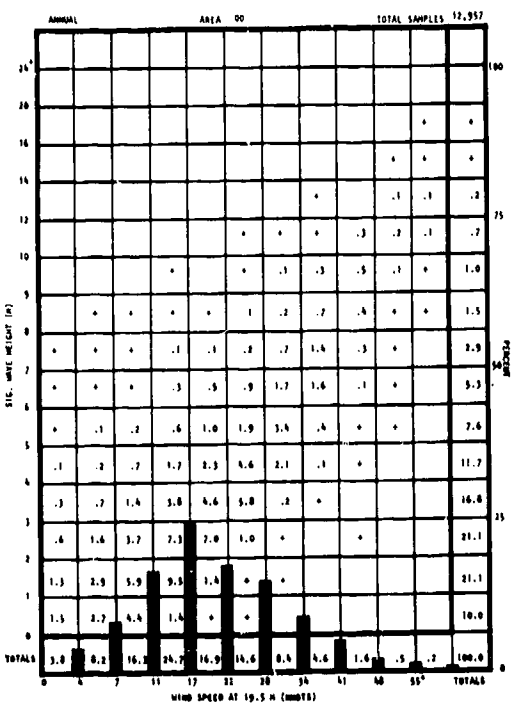


Figure A-00-1-2 Significant Wave Height by Wind Speed

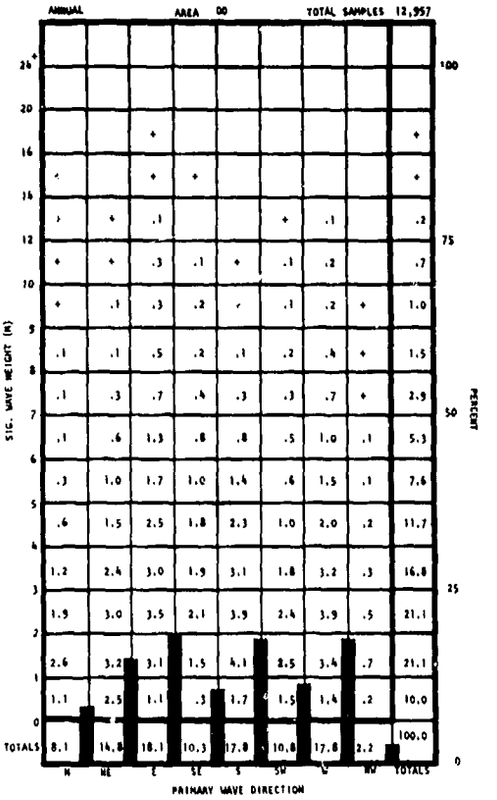


Figure A-00-1-3 Significant Wave Height by Wave Direction

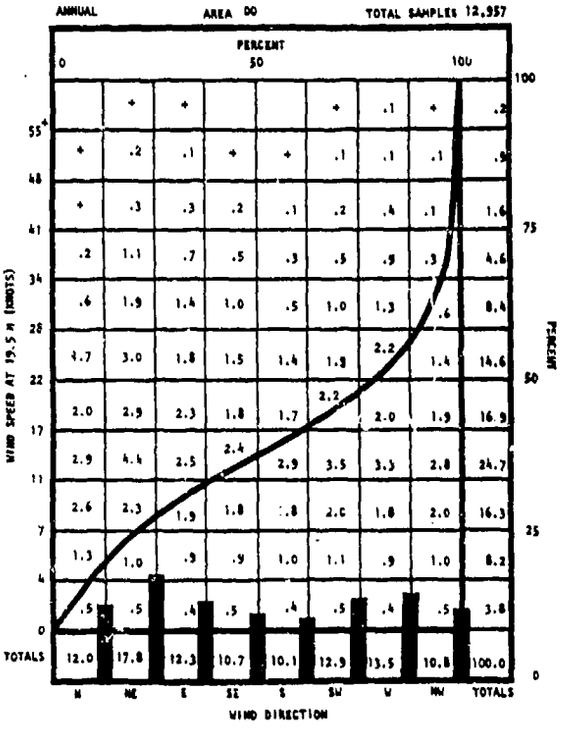


Figure A-00-1-4 Wind Speed by Wind Direction

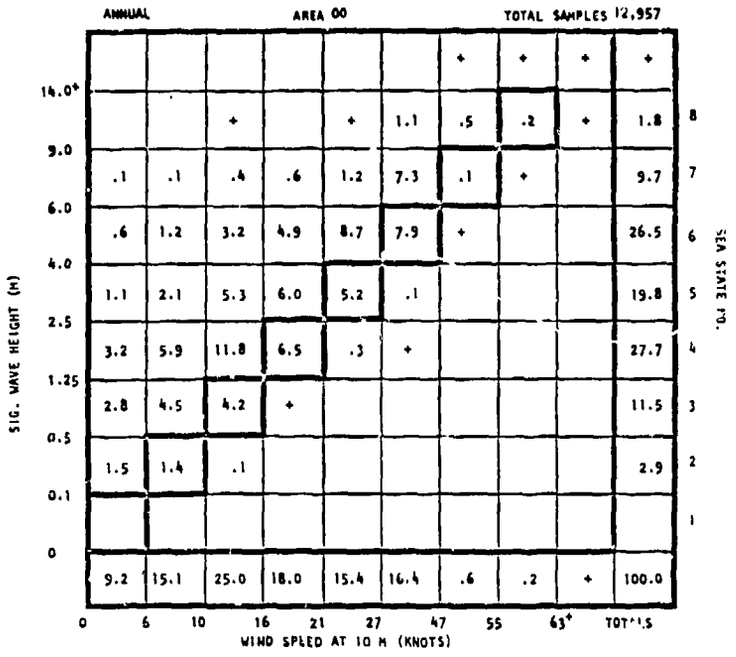


Figure A-00-1-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

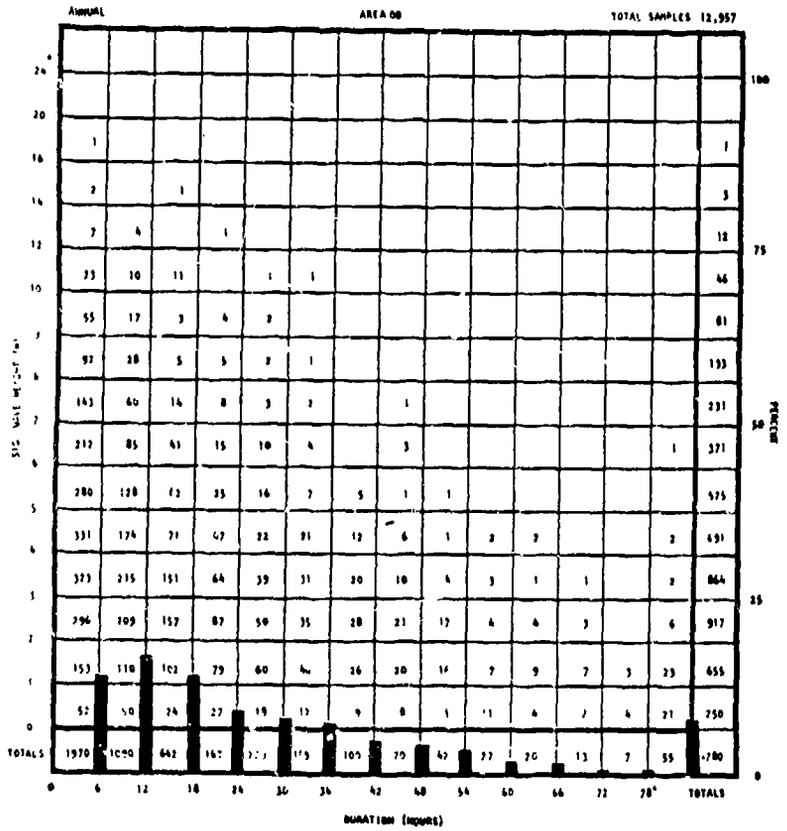


Figure A-00-1-6 Persistence of Significant Wave Height

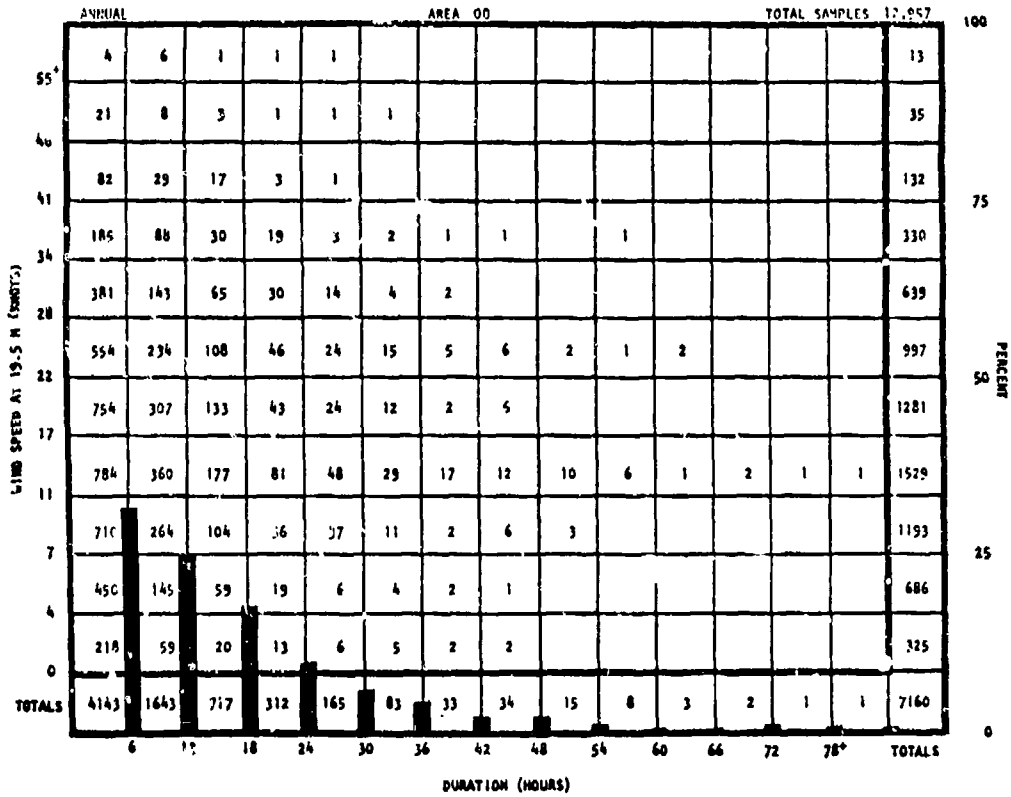


Figure A-00-1-7 Persistence of Wind Speed

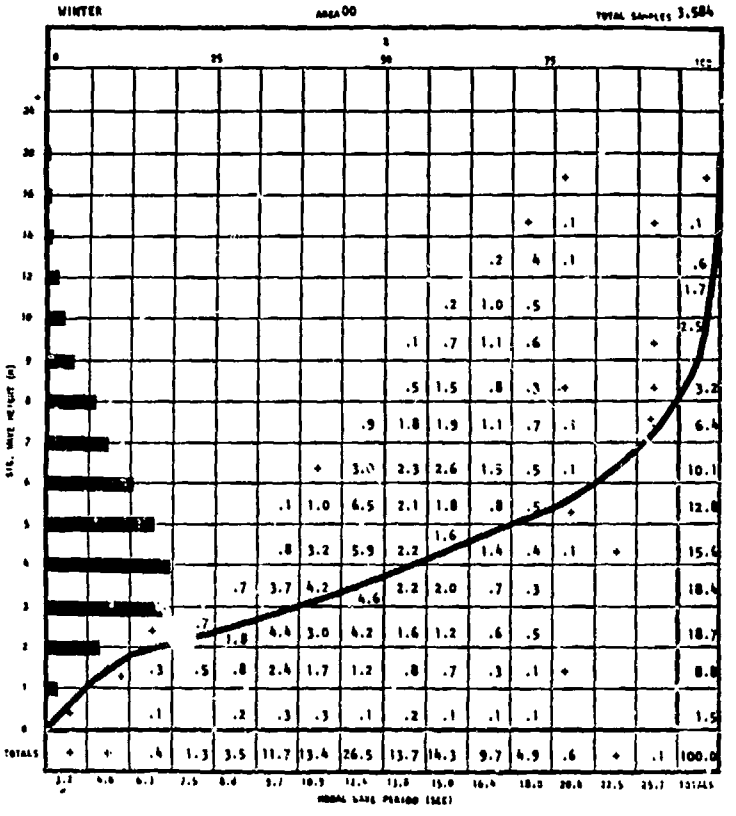


Figure A-00-2-1 Significant Wave Height by Modal Wave Period

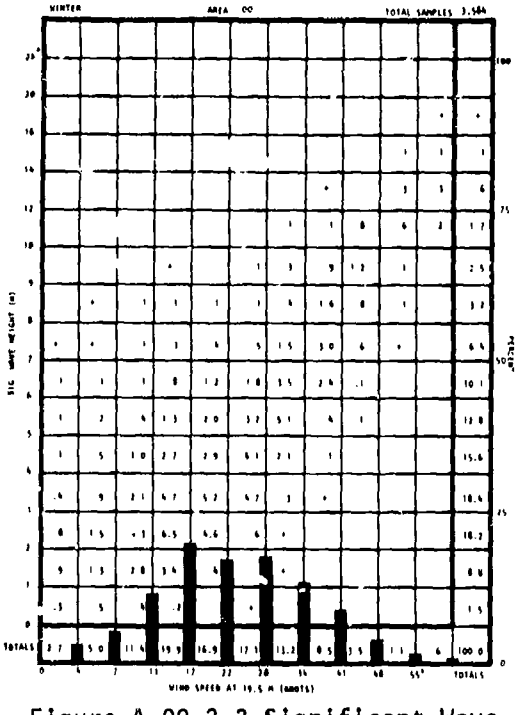


Figure A-00-2-2 Significant Wave Height by Wind Speed

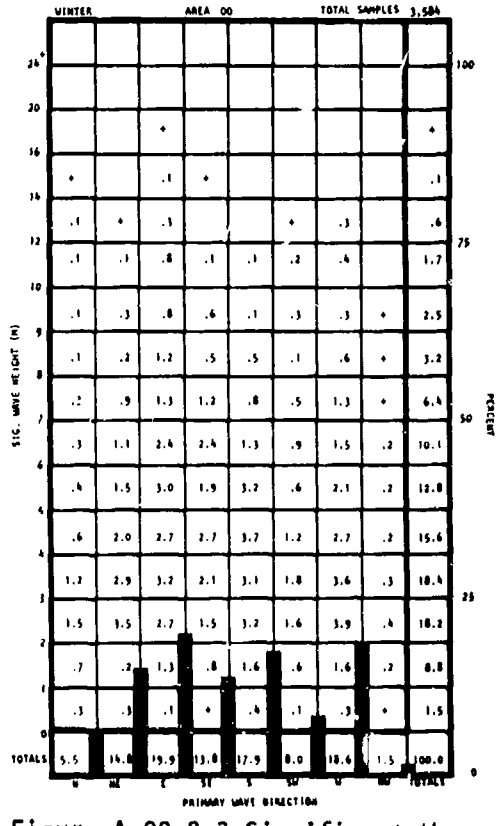


Figure A-00-2-3 Significant Wave Height by Wave Direction

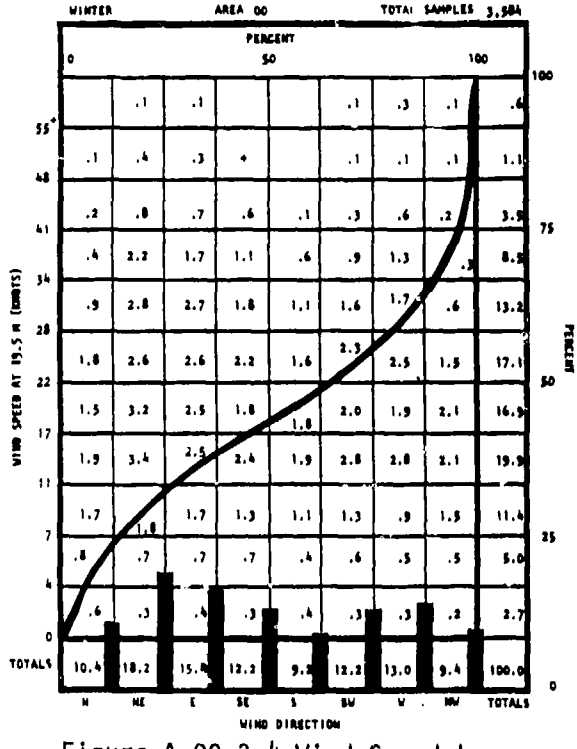


Figure A-00-2-4 Wind Speed by Wind Direction

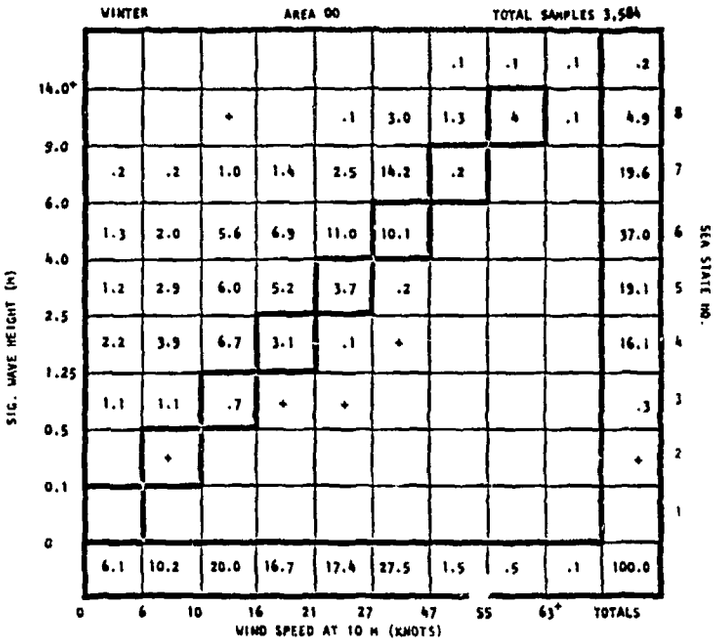


Figure A-00-2-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

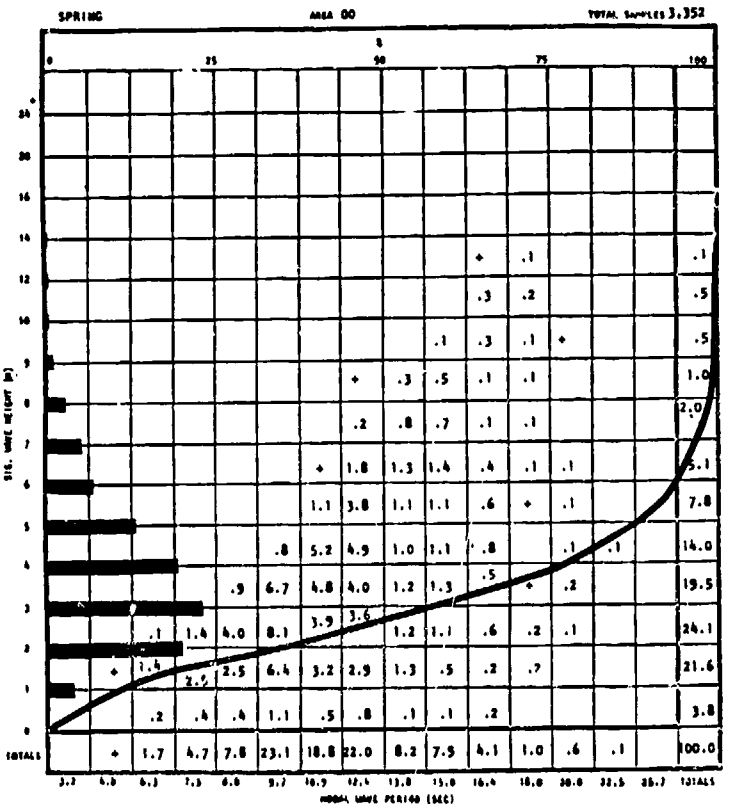


Figure A-00-3-1 Significant Wave Height by Modal Wave Period

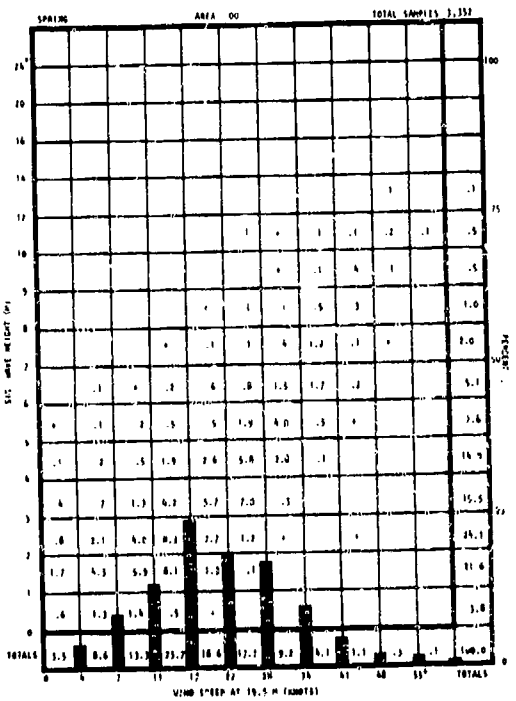


Figure A-00-3-2 Significant Wave Height by Wind Speed

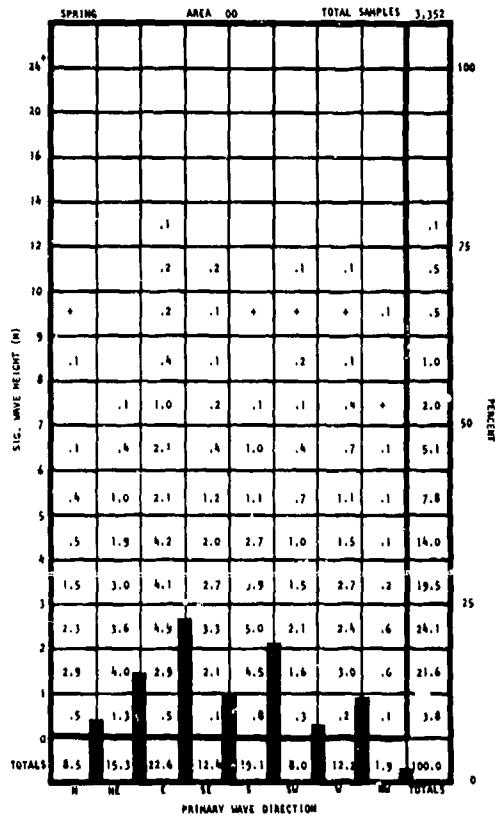


Figure A-00-3-3 Significant Wave Height by Wave Direction

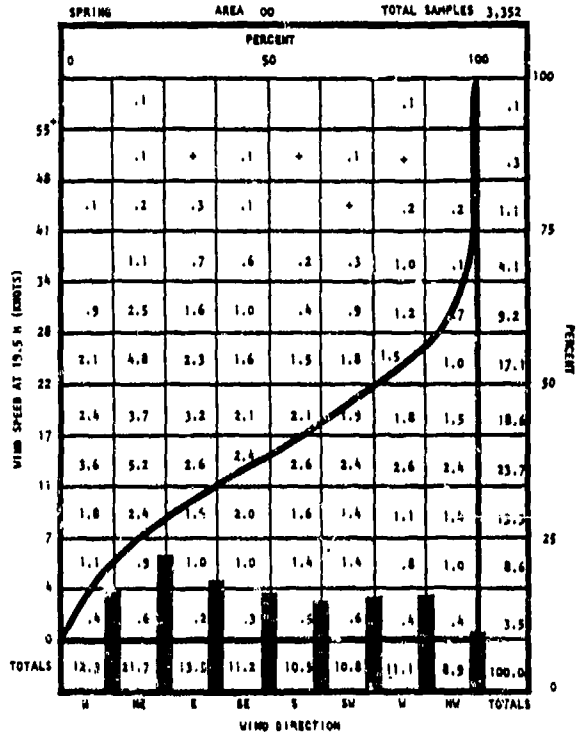


Figure A-00-3-4 Wind Speed by Wind Direction

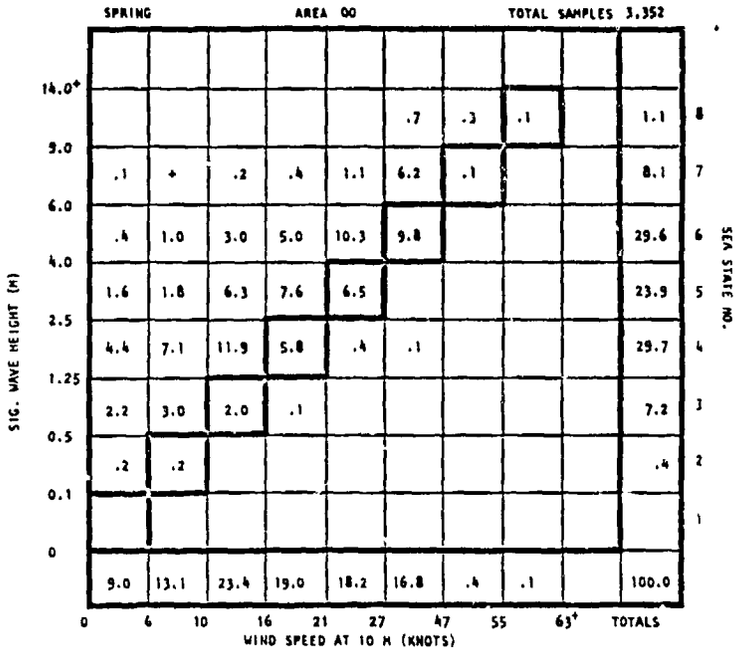


Figure A-00-3-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

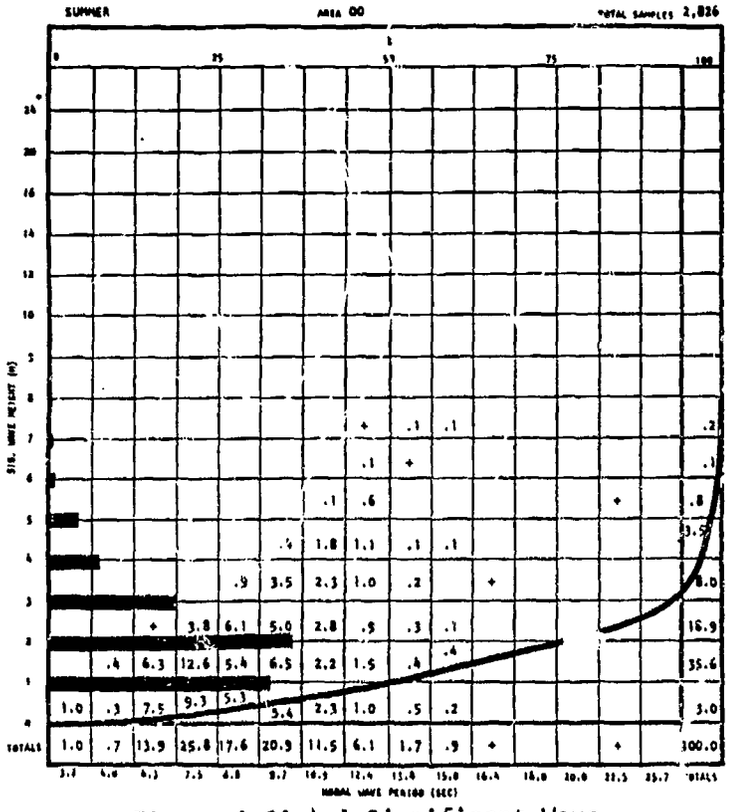


Figure A-00-4-1 Significant Wave Height by Modal Wave Period

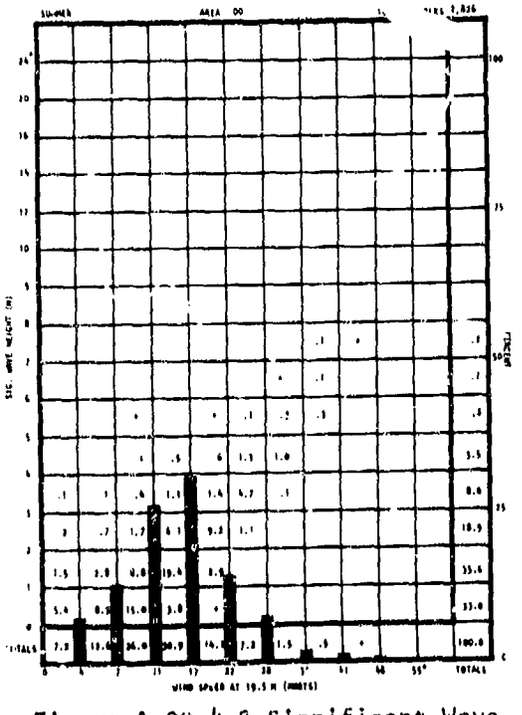


Figure A-00-4-2 Significant Wave Height by Wind Speed

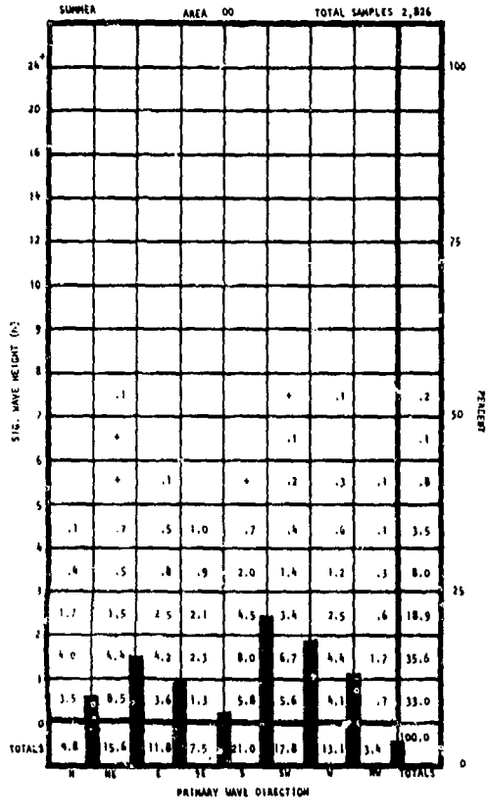


Figure A-00-4-3 Significant Wave Height by Wave Direction

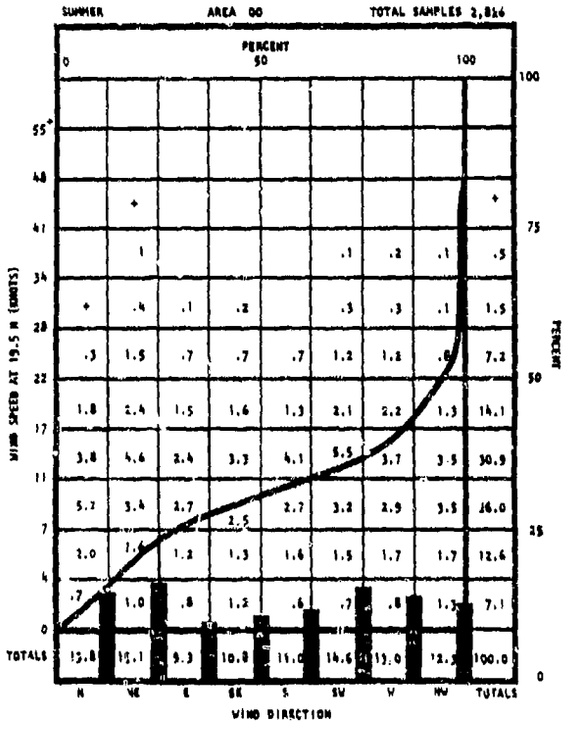


Figure A-00-4-4 Wind Speed by Wind Direction

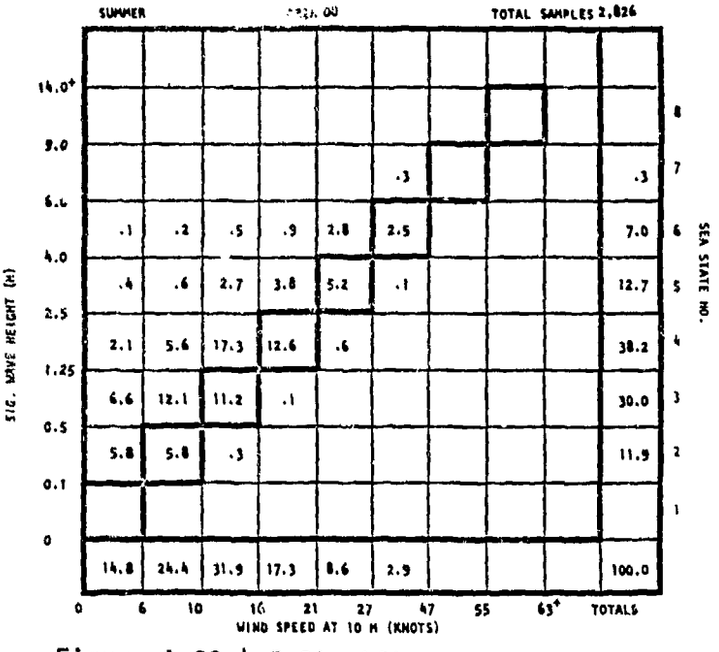


Figure A-00-4-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

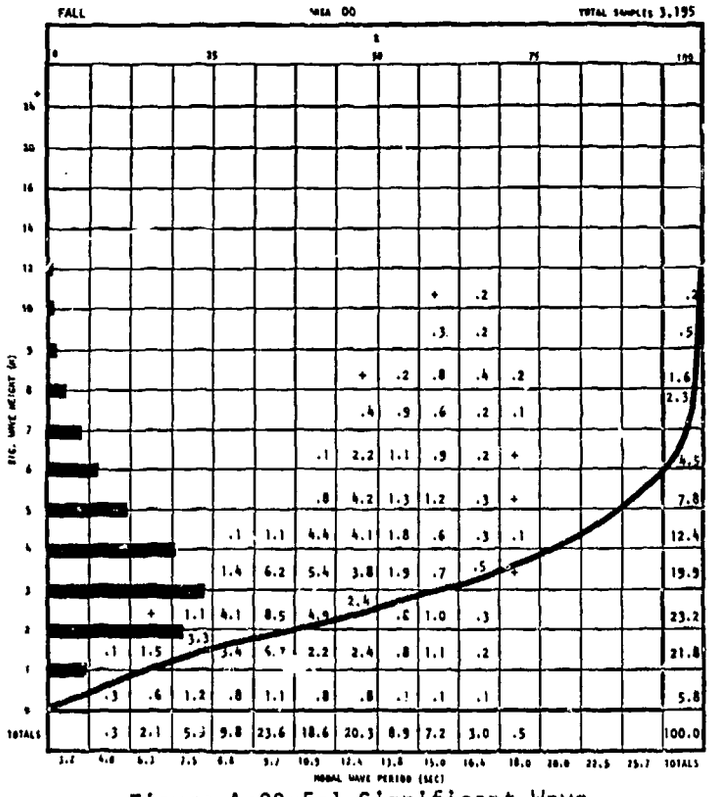


Figure A-00-5-1 Significant Wave Height by Modal Wave Period

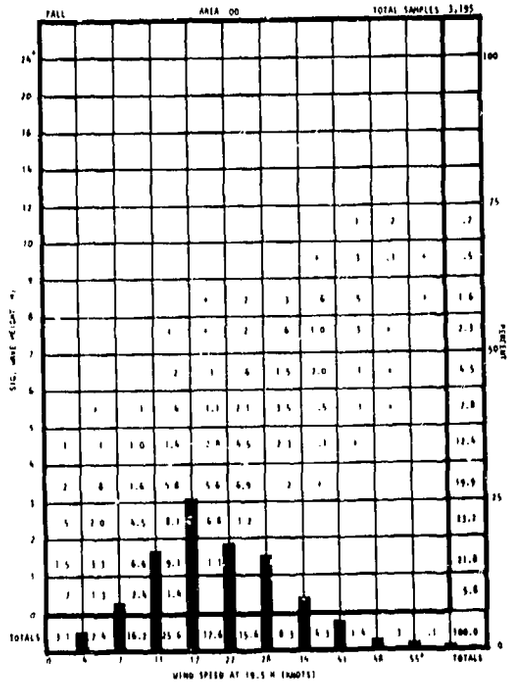


Figure A-00-5-2 Significant Wave Height by Wind Speed

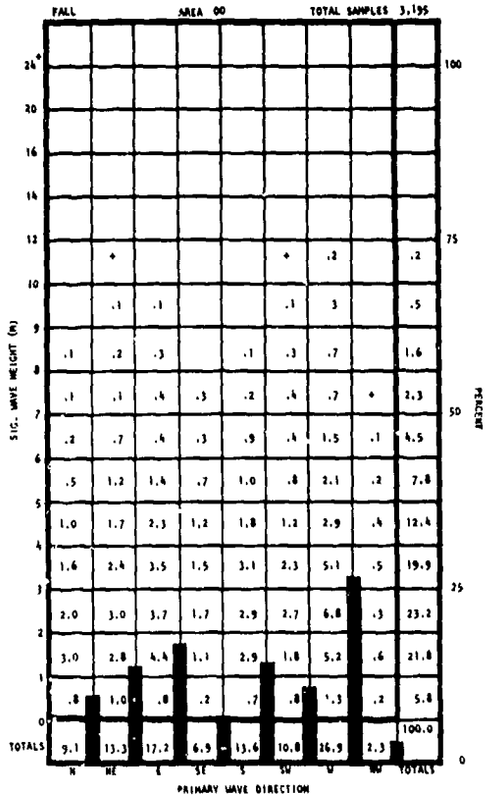


Figure A-00-5-3 Significant Wave Height by Wave Direction

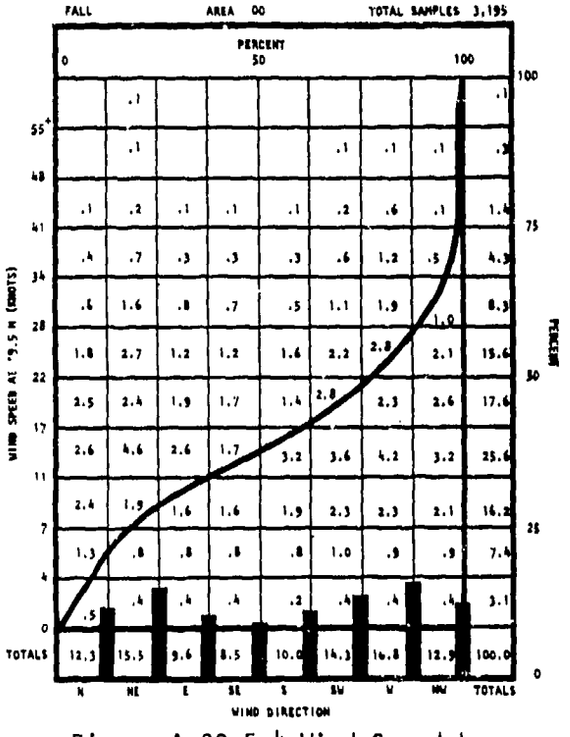


Figure A-00-5-4 Wind Speed by Wind Direction

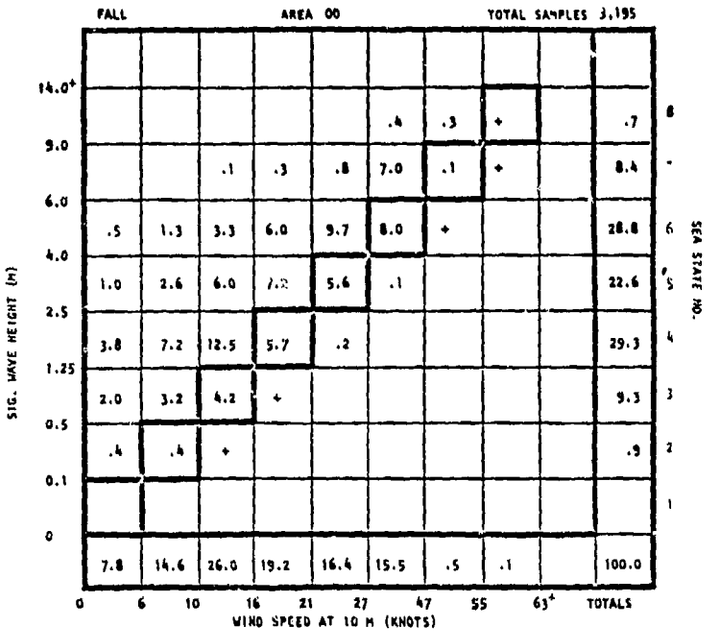


Figure A-00-5-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

TABLE A-1-1-1 - SURFACE NATURAL ENVIRONMENT SUMMARY

Season: Annual; Location: 52.755° N, 33.765° W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface Sig. Wave Height, m. Wave Period, sec Direction	1 6.5 -	3 10.5 -	7.5 16 -	3.5 11 -	2.5 12.5 S - W
Winds Speed, knots Corresponding Mean Sig. Wave Height, m. Direction	5 1.5 -	17 3 -	36 7.5 -	18 3 -	14 2.5 SW - W
Visibility, nautical miles	1.5	9	22	-	-
Cloud Cover Total clouds, in eighths of sky obscured Low clouds, in eighths of sky obscured	1 1	7 6.5	8 8	- -	- -
Precipitation (Occurrence)	All precipitation - 25% of the time		Snow - 6% of the time (Dec - Mar)		
Relative Humidity, %	60	82	98	-	-
Air Temperature, °C	3.5	8	12.5	8	-
Surface Water Temperature, °C	6	8.5	13	-	-
Sea Level Pressure, millibars	987	1,009	1,028	-	-
Ice	None				
Refractivity Mean Surface Refractivity Sub-Refraction (1 km, Annual) Super-Refraction or Ducting (1 km, Annual)	- - -	- - -	- - -	322 - -	- 1% of the time None

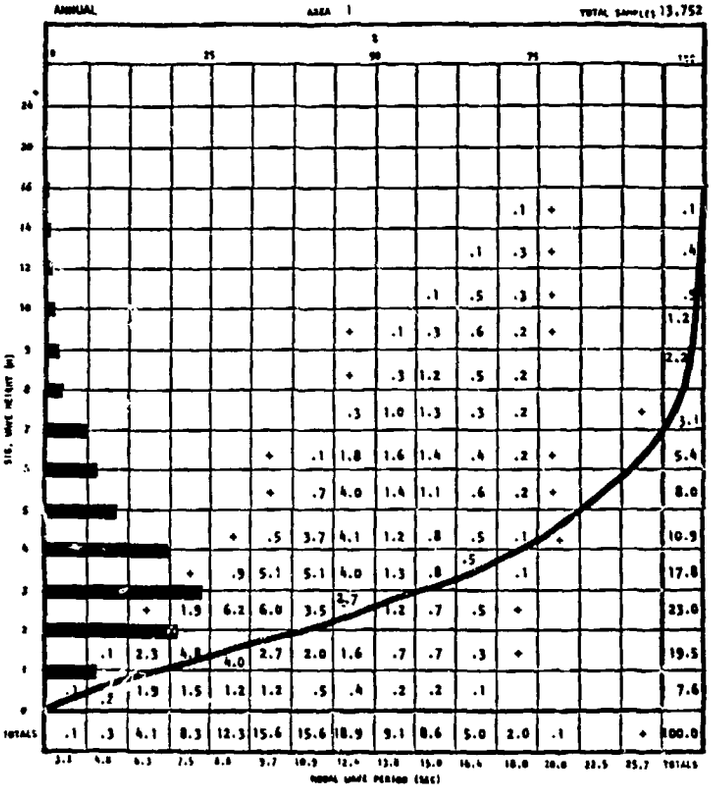


Figure A-1-1-1 Significant Wave Height by Modal Wave Period

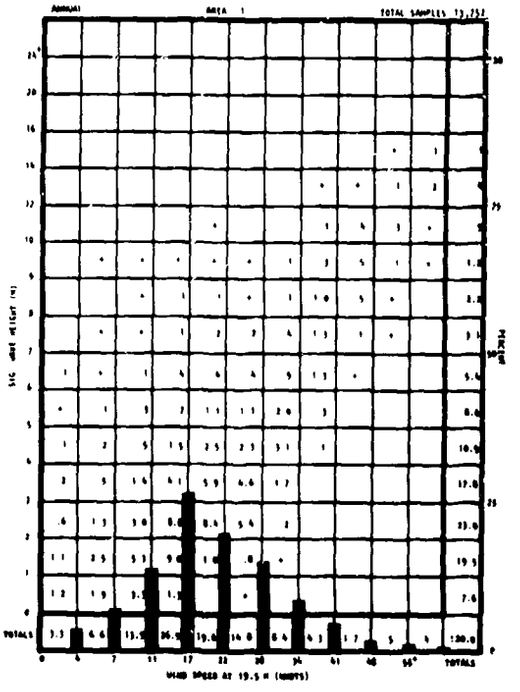


Figure A-1-1-2 Significant Wave Height by Wind Speed

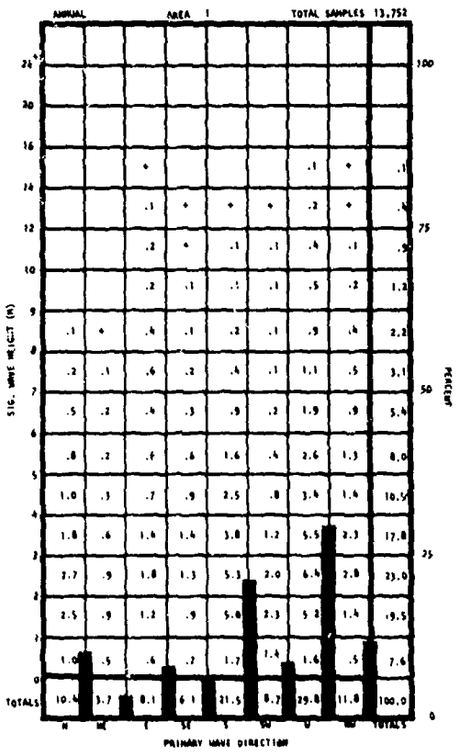


Figure A-1-1-3 Significant Wave Height by Wave Direction

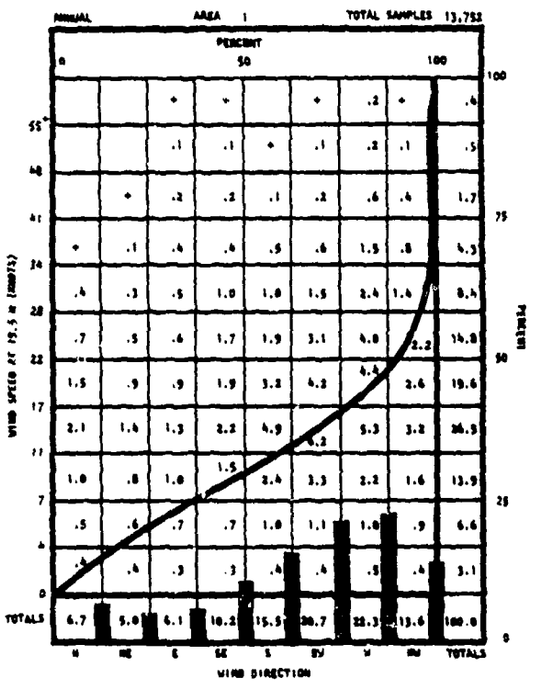


Figure A-1-1-4 Wind Speed by Wind Direction

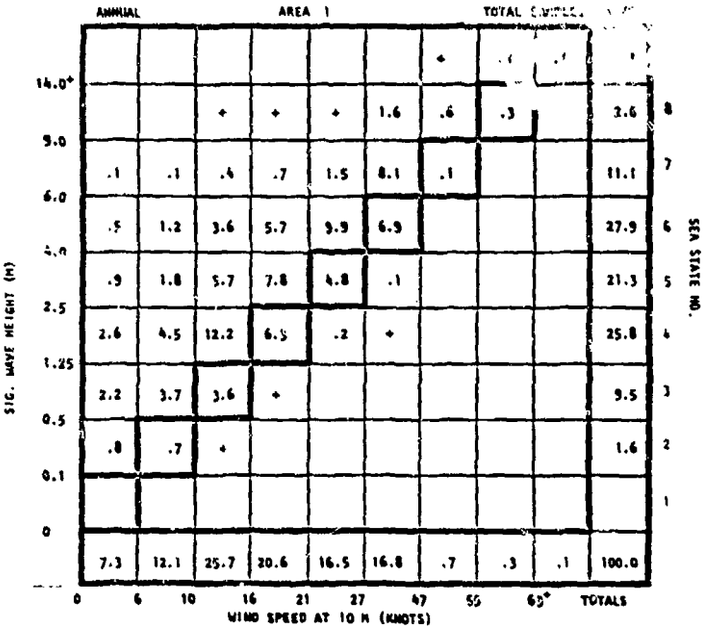


Figure A-1-1-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

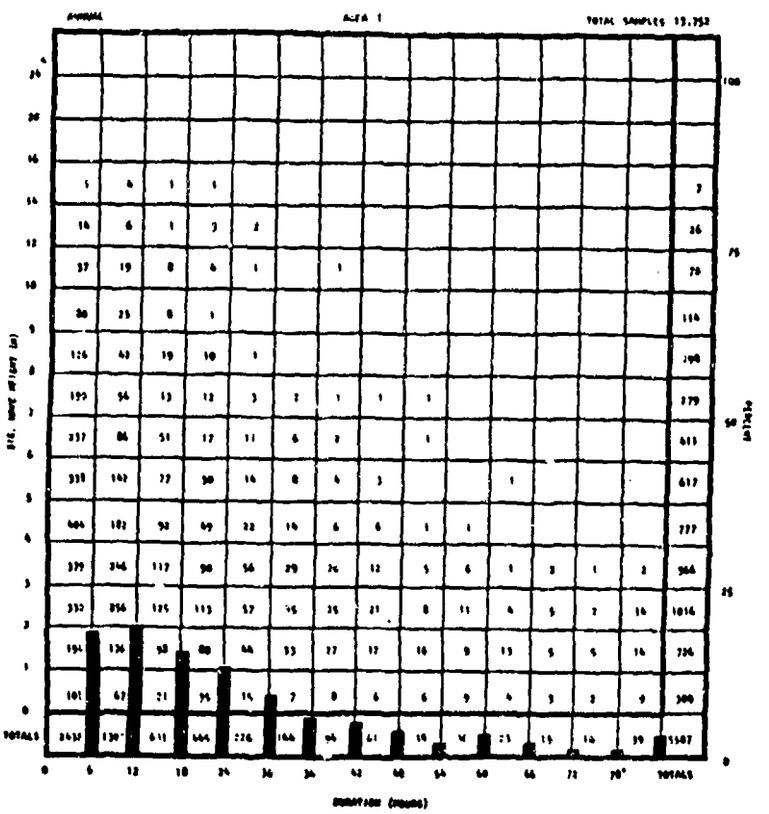


Figure A-1-1-6 Persistence of Significant Wave Height

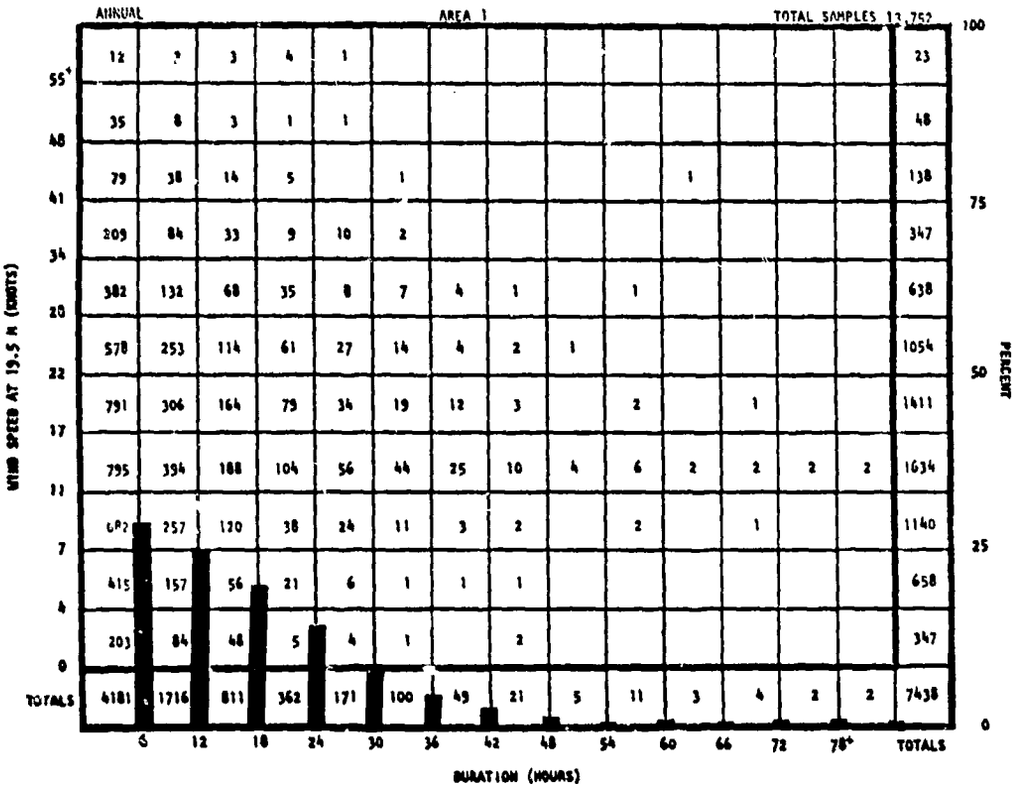


Figure A-1-1-7 Persistence of
Wind Speed

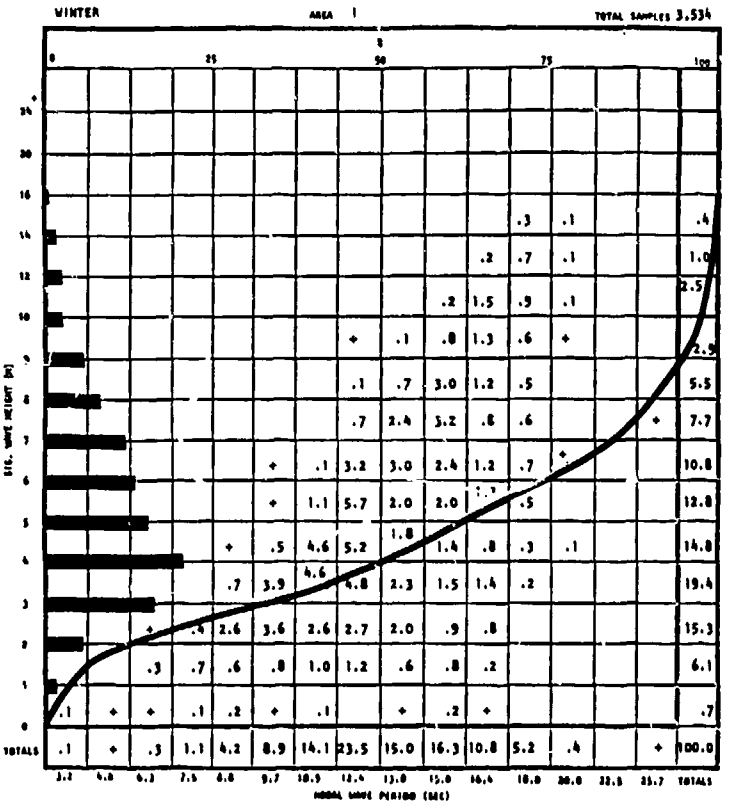


Figure A-1-2-1 Significant Wave Height by Modal Wave Period

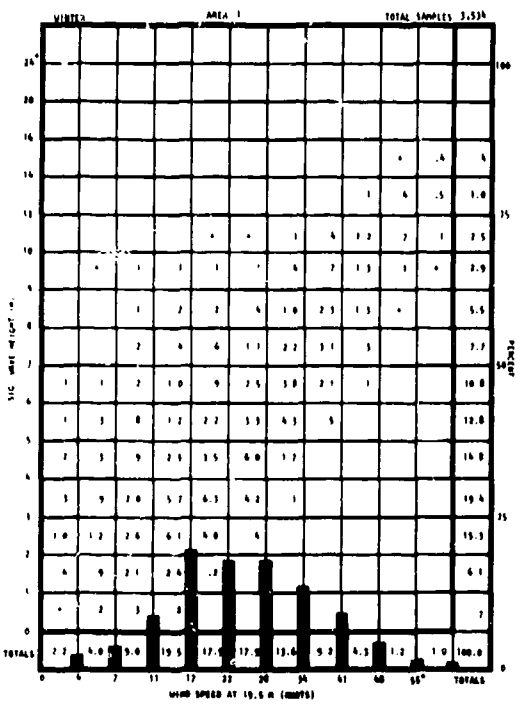


Figure A-1-2-2 Significant Wave Height by Wind Speed

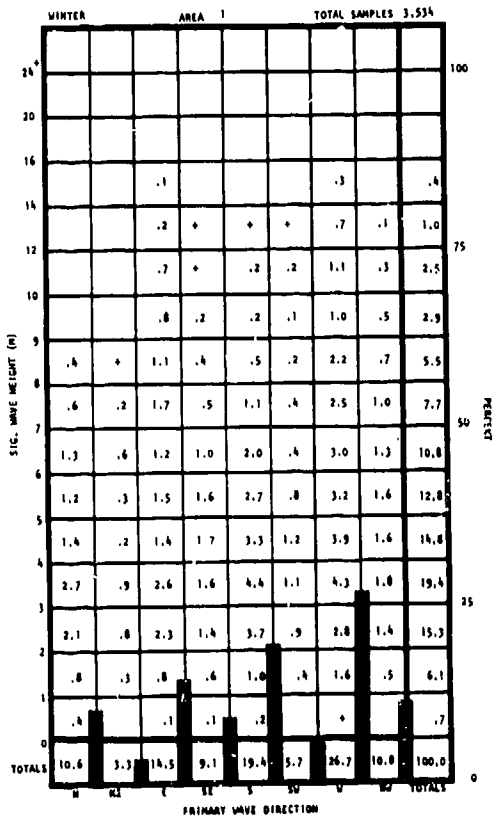


Figure A-1-2-3 Significant Wave Height by Wave Direction

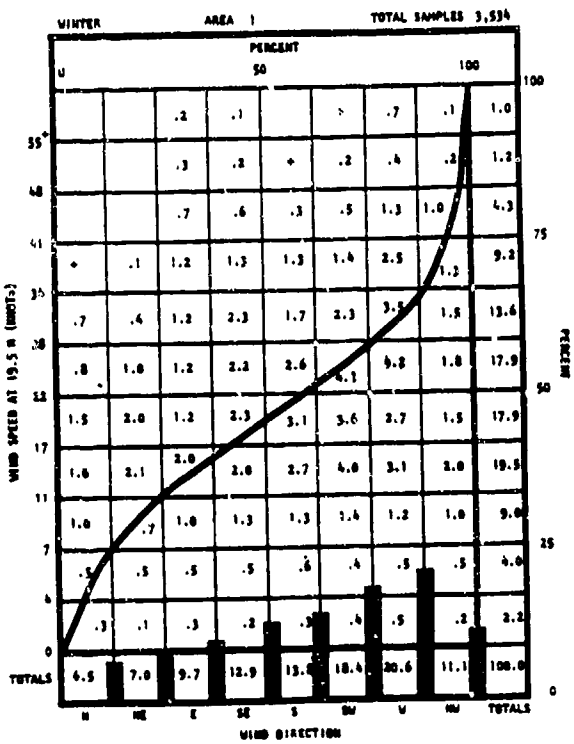
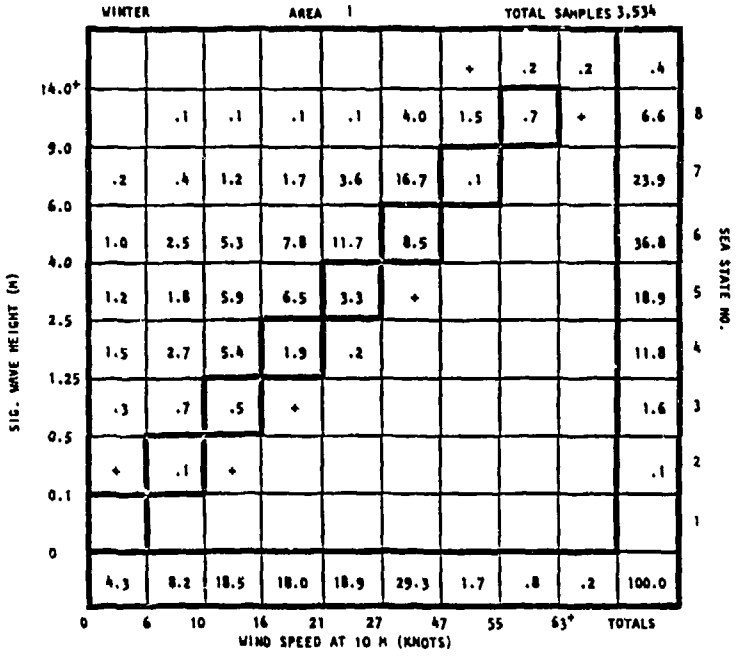


Figure A-1-2-4 Wind Speed by Wind Direction



						+	.2	.2	.4
	.1	.1	.1	.1	4.0	1.5	.7	+	6.6
.2	.4	1.2	1.7	3.6	16.7	.1			23.9
1.0	2.5	5.3	7.8	11.7	8.5				36.8
1.2	1.8	5.9	6.5	3.3	+				18.9
1.5	2.7	5.4	1.9	.2					11.8
.3	.7	.5	+						1.6
+	.1	+							.1
4.3	8.2	18.5	18.0	18.9	29.3	1.7	.8	.2	100.0

Figure A-1-2-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

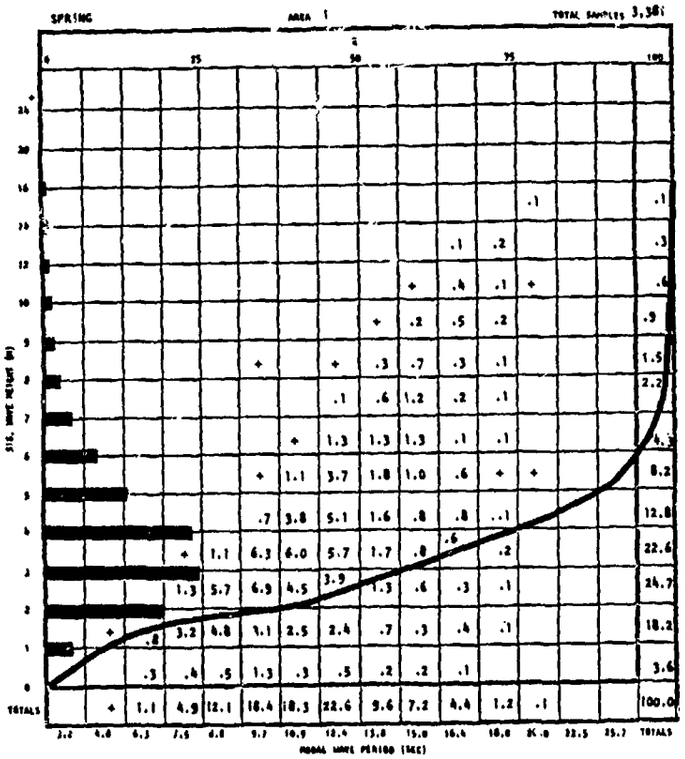


Figure A-1-3-1 Significant Wave Height by Modal Wave Period

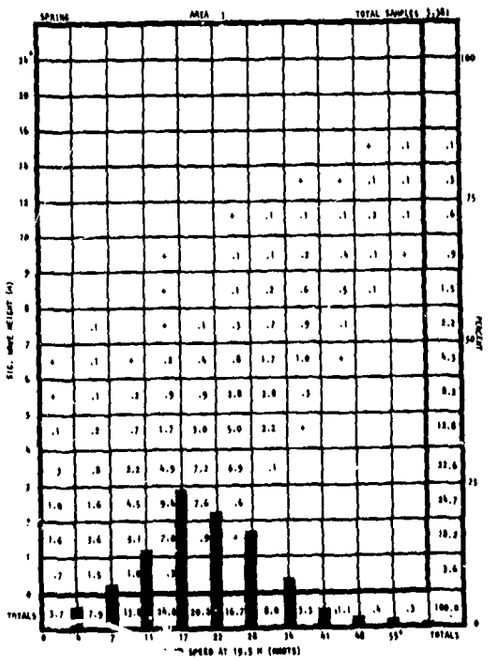


Figure A-1-3-2 Significant Wave Height by Wind Speed

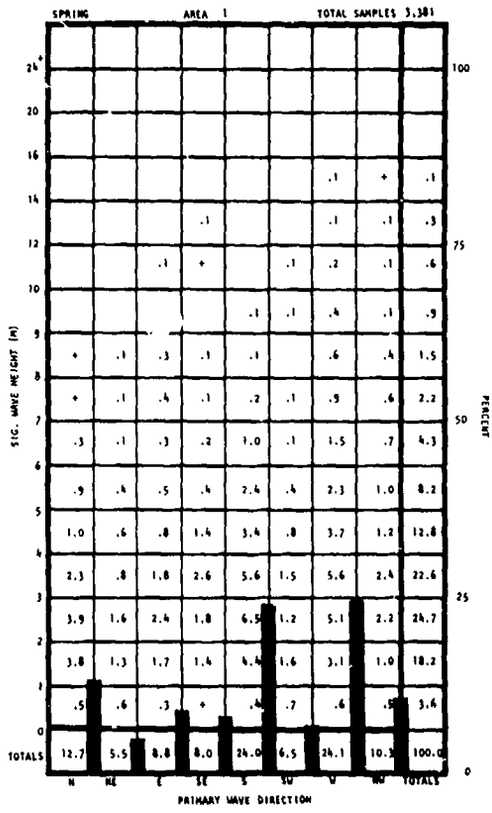


Figure A-1-3-3 Significant Wave Height by Wave Direction

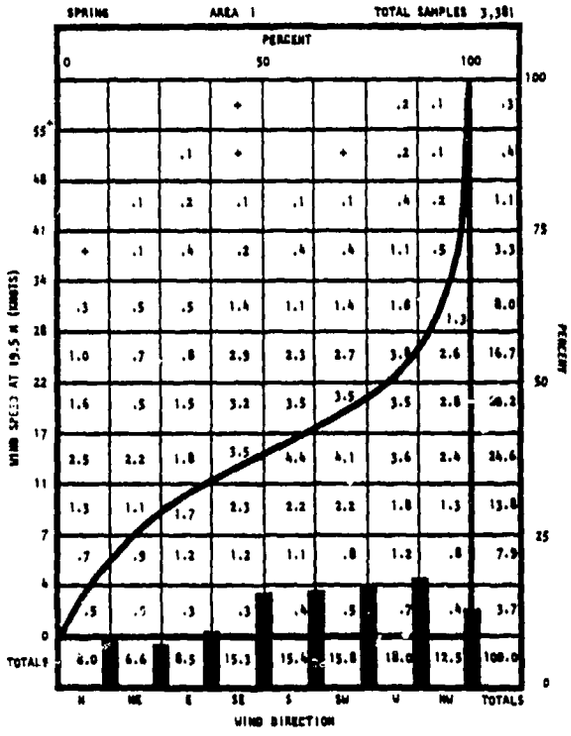


Figure A-1-3-4 Wind Speed by Wind Direction

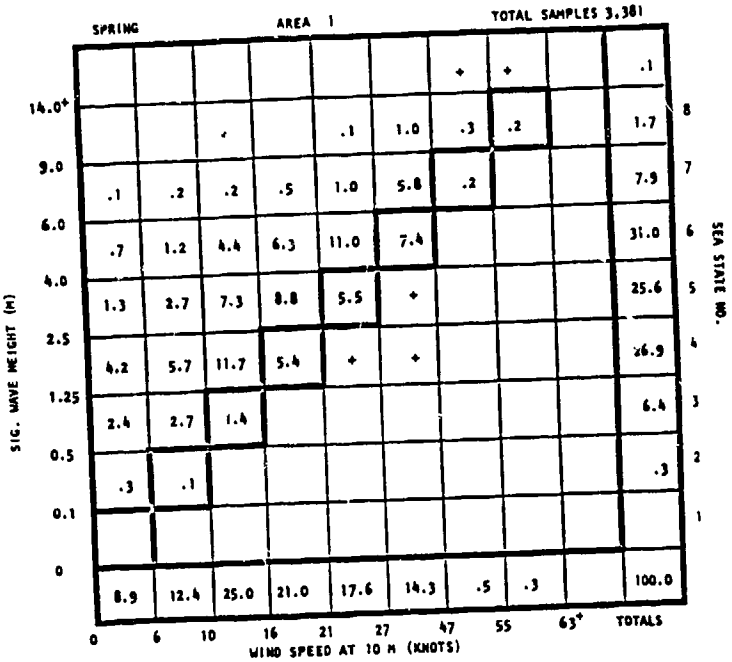


Figure A-1-3-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

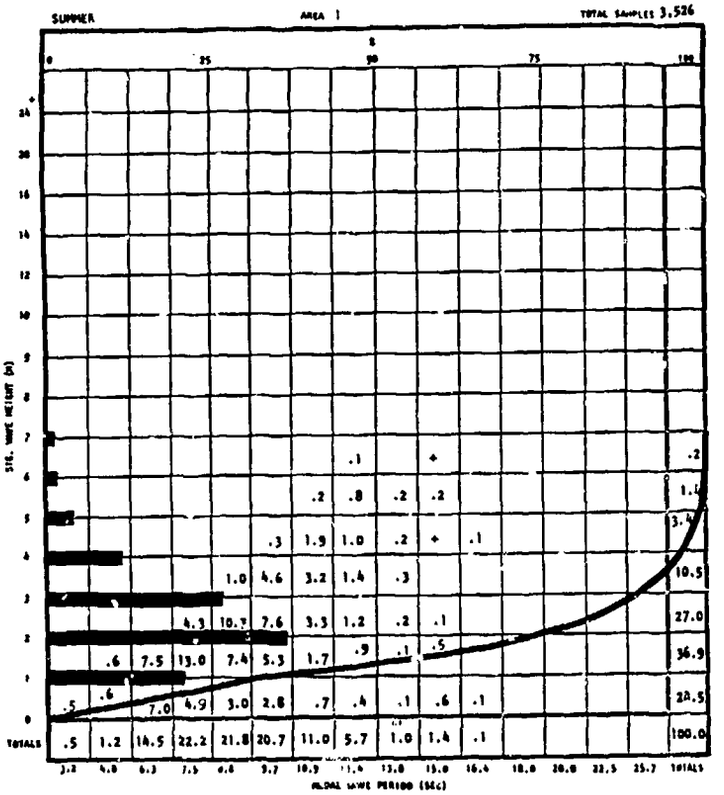


Figure A-1-4-1 Significant Wave Height by Modal Wave Period

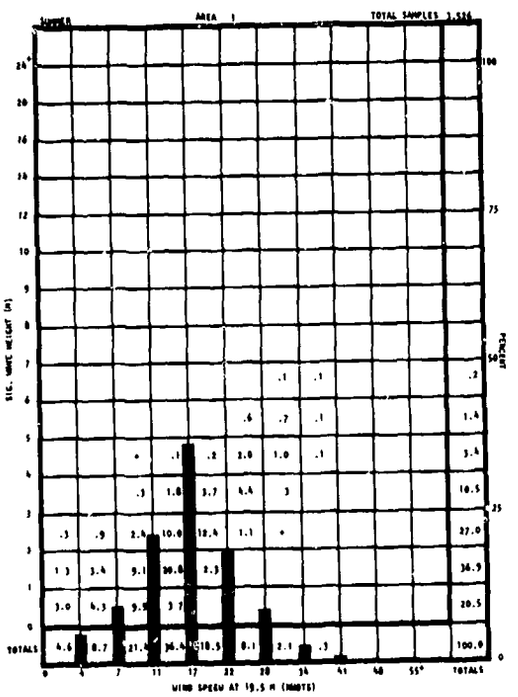


Figure A-1-4-2 Significant Wave Height by Wind Speed

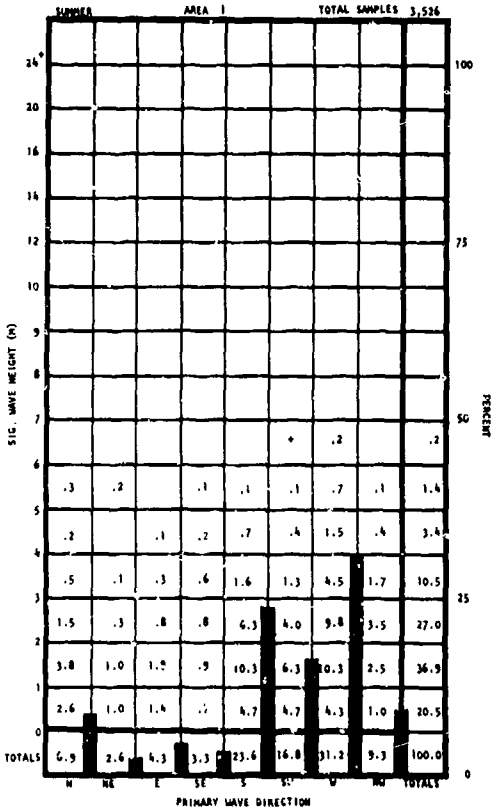


Figure A-1-4-3 Significant Wave Height by Wave Direction

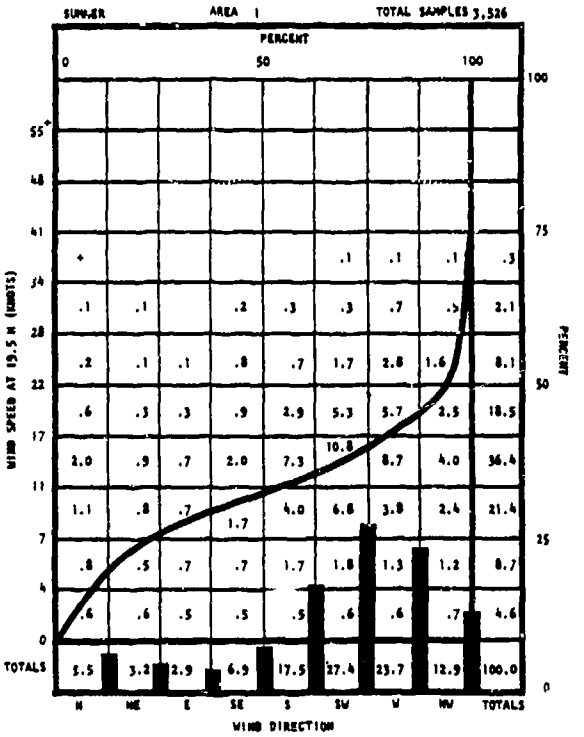


Figure A-1-4-4 Wind Speed by Wind Direction

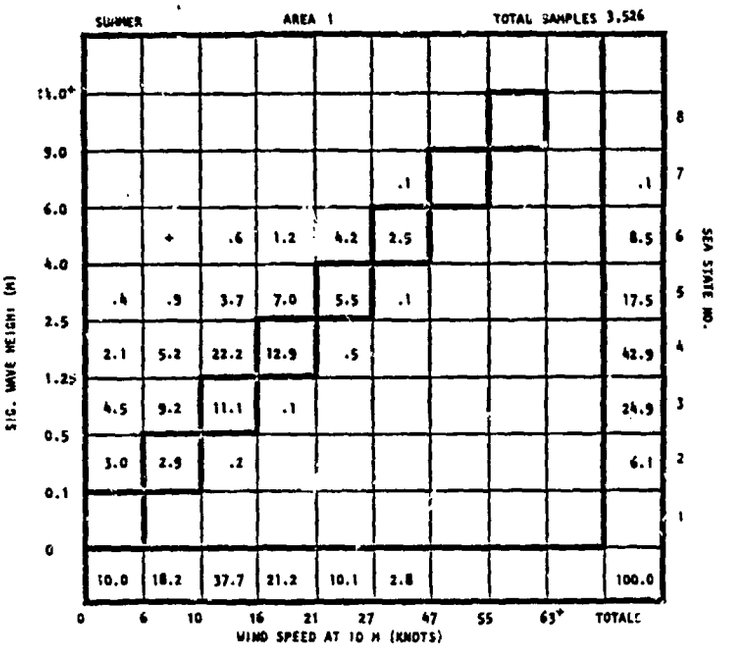


Figure A-1-4-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

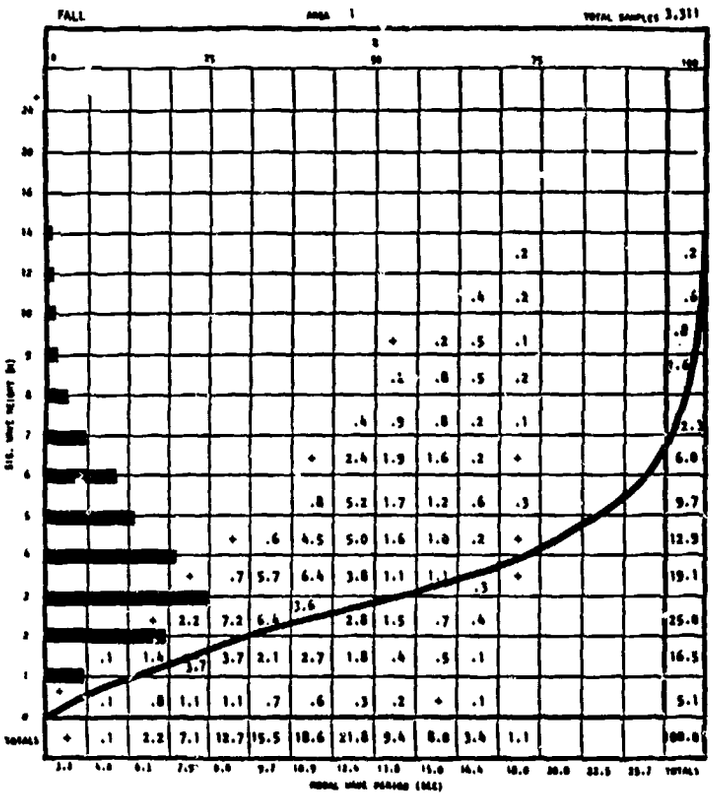


Figure A-1-5-1 Significant Wave Height by Modal Wave Period

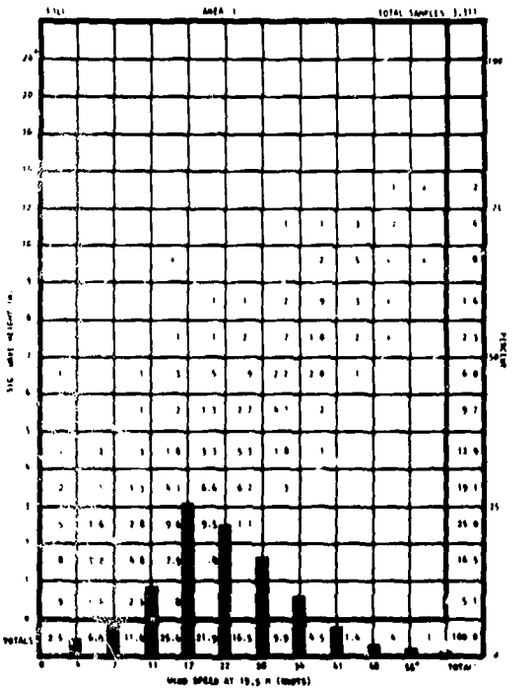


Figure A-1-5-2 Significant Wave Height by Wind Speed

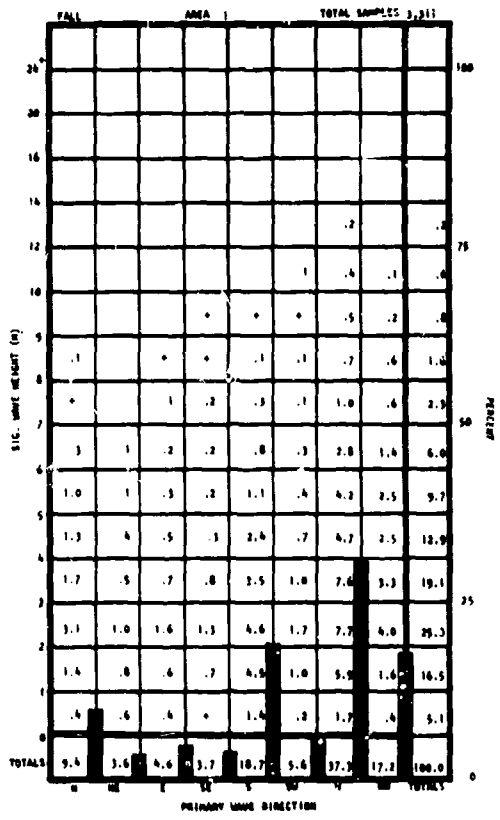


Figure A-1-5-3 Significant Wave Height by Wave Direction

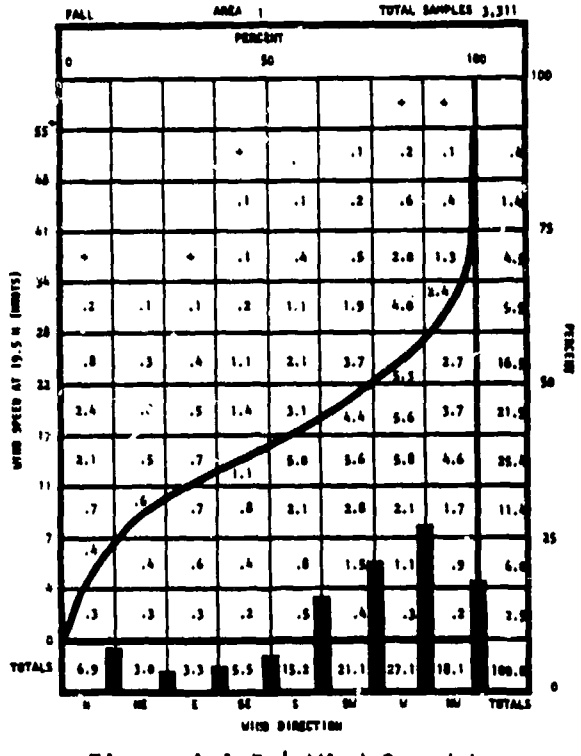


Figure A-1-5-4 Wind Speed by Wind Direction

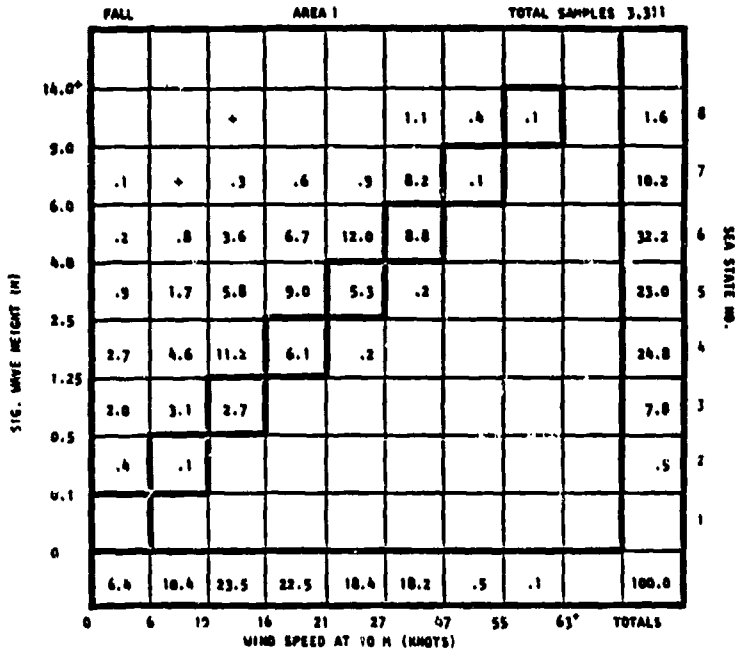


Figure A-1-5-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

TABLE A-2-1-1 - SURFACE NATURAL ENVIRONMENT SUMMARY

Season: Annual; Location: 58.3°N, 12.3°W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface Sig. Wave Height, m. Wave Period, sec Direction	 .5 6.5 -	 3 11 -	 7.5 16 -	 3 11 -	 2 12.5 SW - W
Winds Speed, knots Corresponding Mean Sig. Wave Height, m. Direction	 5 1 -	 16 2.5 -	 40 7.5 -	 18 3 -	 15 2.5 SW
Visibility, nautical miles	3	10	25	-	-
Cloud Cover Total clouds, in eighths of sky obscured Low clouds, in eighths of sky obscured	 1 1	 6.5 5.5	 8 8	 - -	 - -
Precipitation (Occurrence)	All precipitation - 22% of the time		Snow - 5% of the time (Dec-Mar)		
Relative Humidity, %	63	85	98	-	-
Air Temperature, °C	6	9.5	14.5	10	-
Surface Water Temperature, °C	9	10.5	14	-	-
Sea Level Pressure, millibars	990	1,011	1,028	-	-
Ice	None				
Refractivity Mean Surface Refractivity Sub-Refraction (1 km, Annual) Super-Refraction or Ducting (1 km, Annual)	 - - -	 - - -	 - - -	 320 - -	 - 1% of the time None

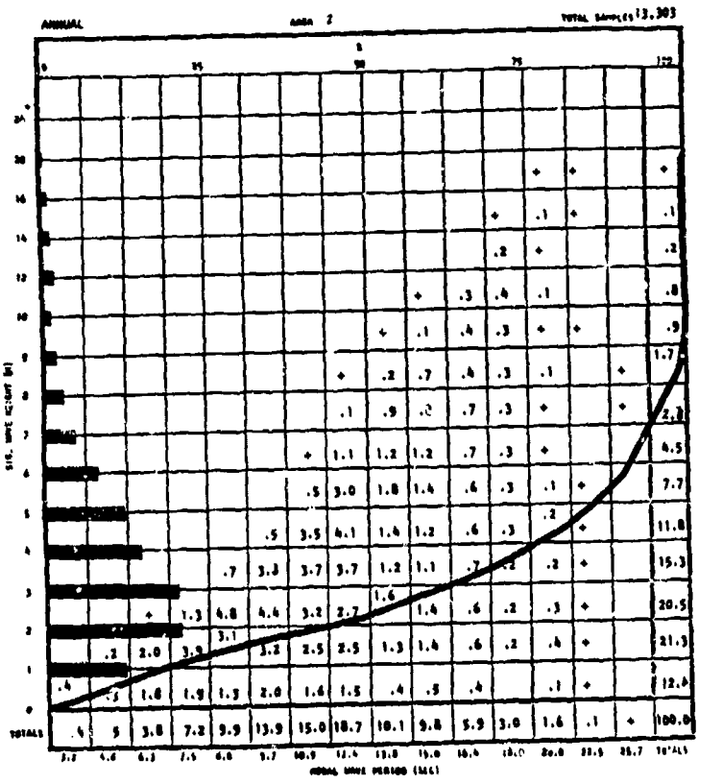


Figure A-2-1-1 Significant Wave Height by Modal Wave Period

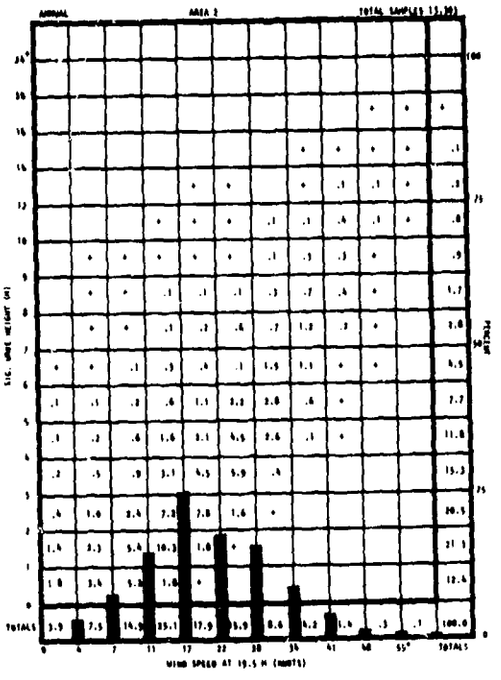


Figure A-2-1-2 Significant Wave Height by Wind Speed

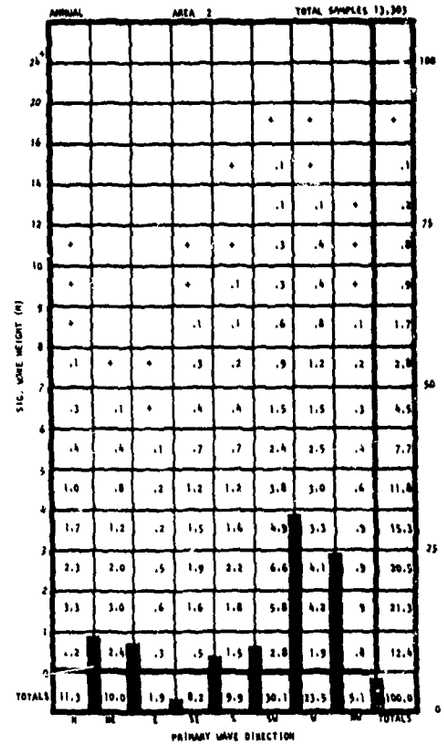


Figure A-2-1-3 Significant Wave Height by Wave Direction

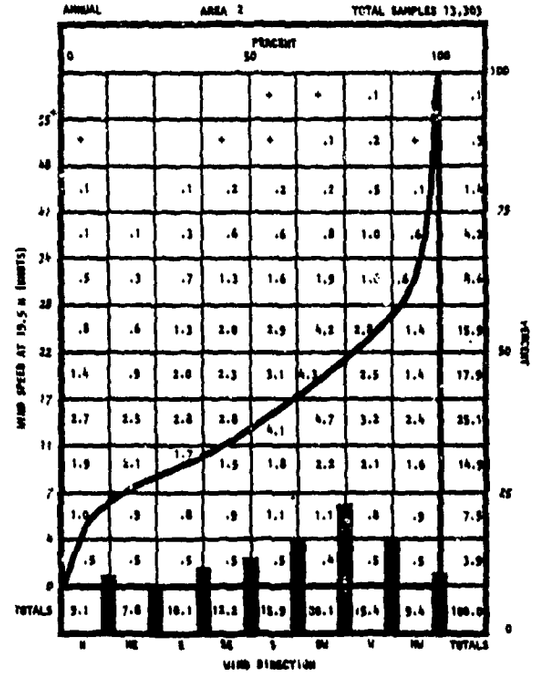


Figure A-2-1-4 Wind Speed by Wind Direction

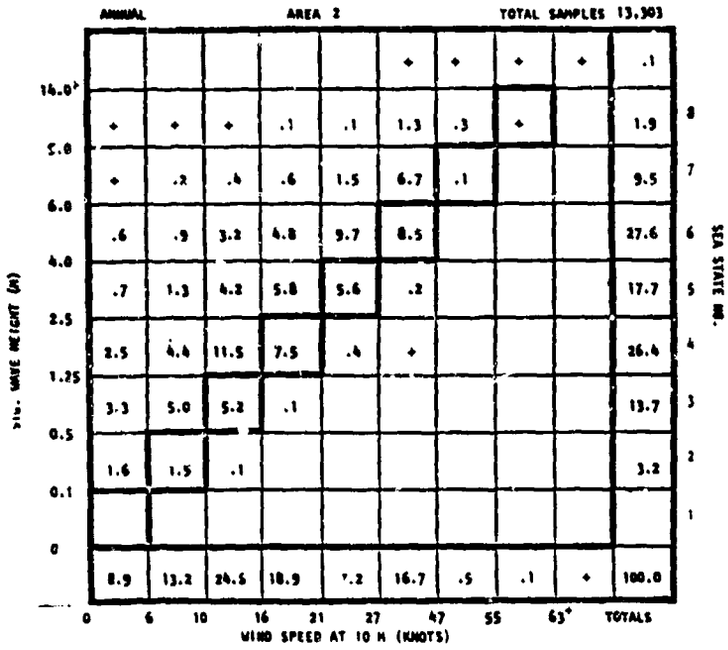


Figure A-2-1-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

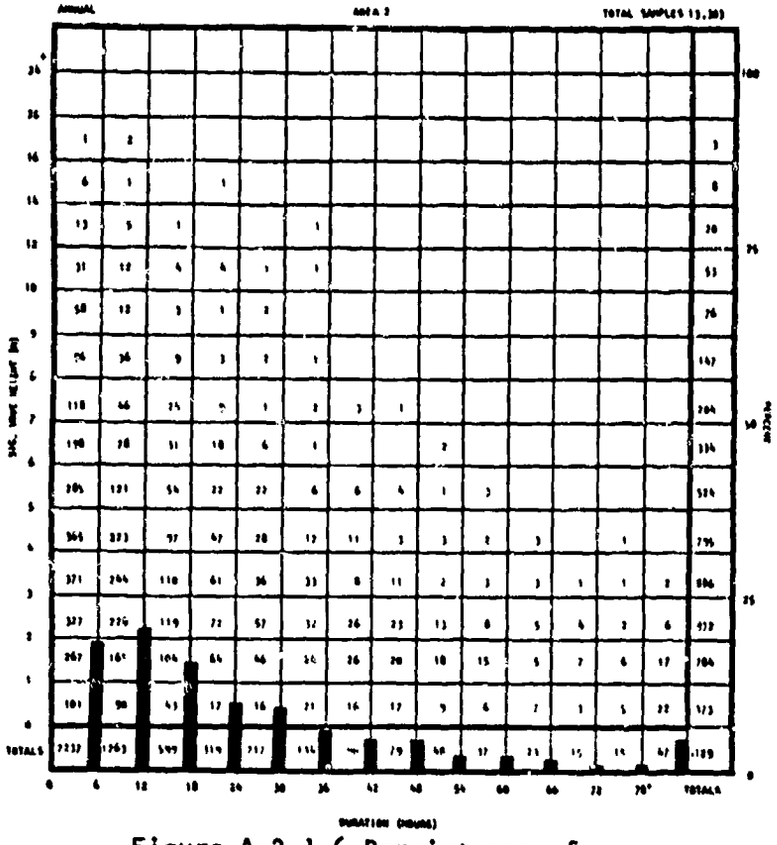


Figure A-2-1-6 Persistence of Significant Wave Height

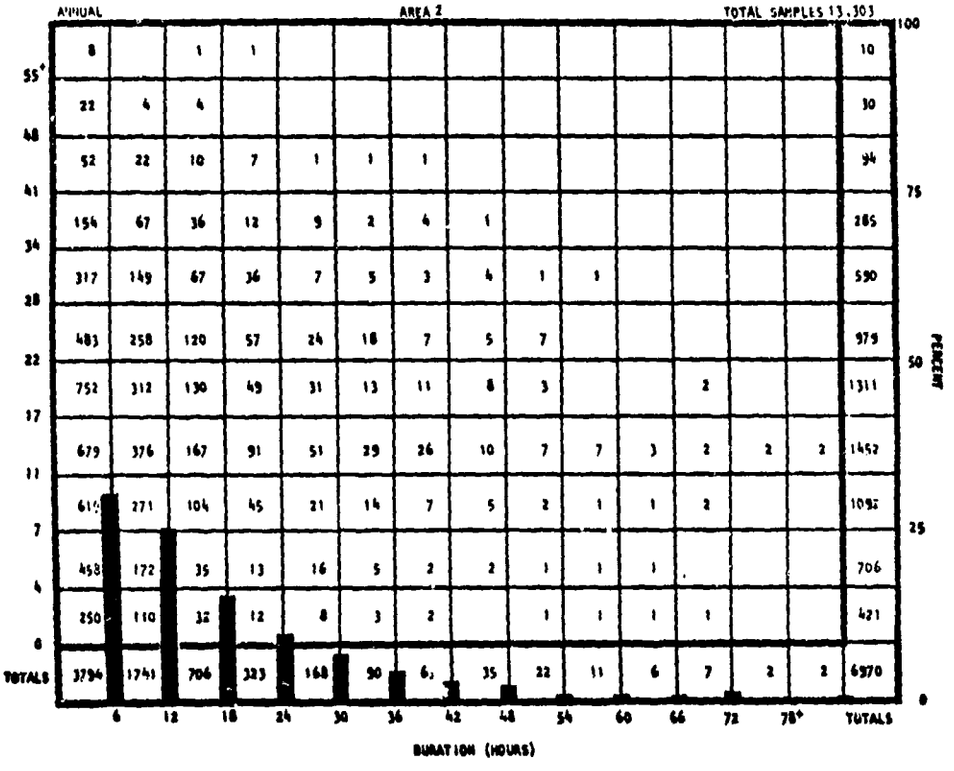


Figure A-2-1-7 Persistence of Wind Speed

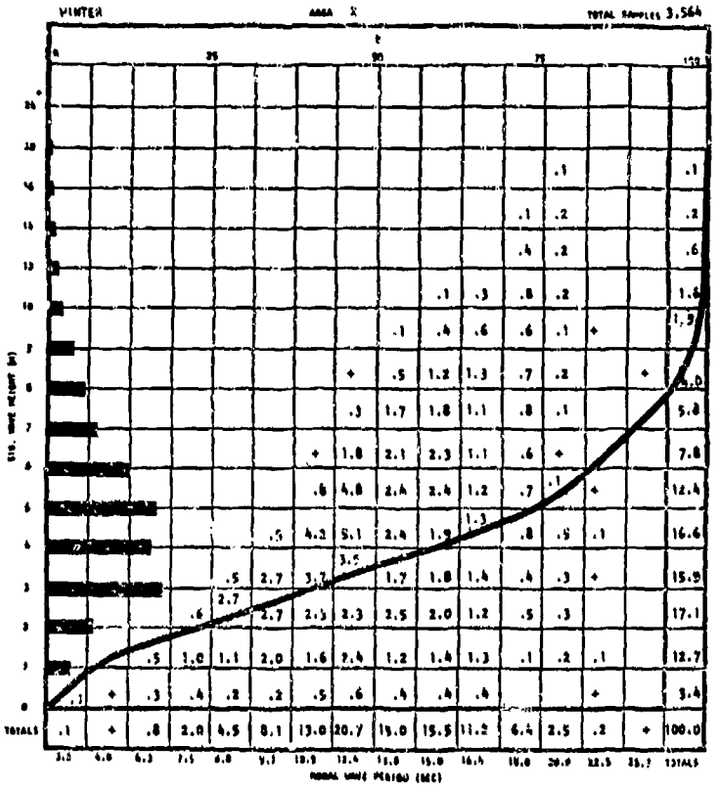


Figure A-2-2-1 Significant Wave Height by Modal Wave Period

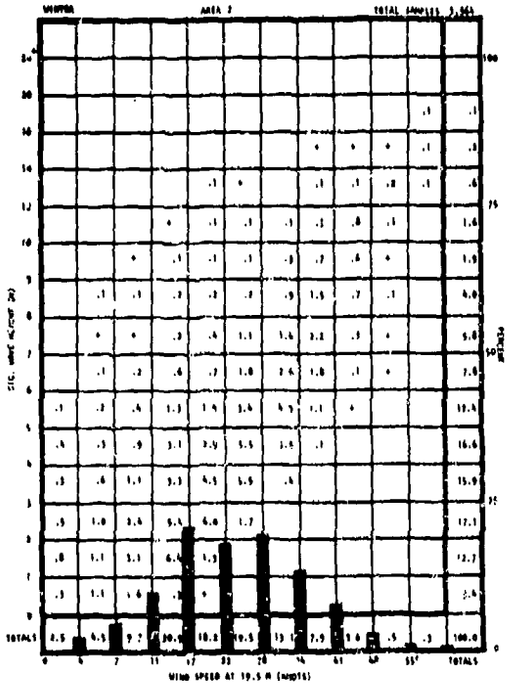


Figure A-2-2-2 Significant Wave Height by Wind Speed

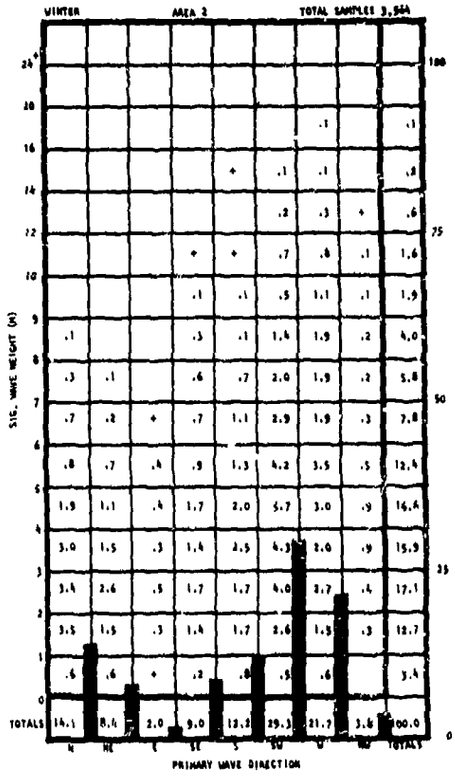


Figure A-2-2-3 Significant Wave Height by Wave Direction

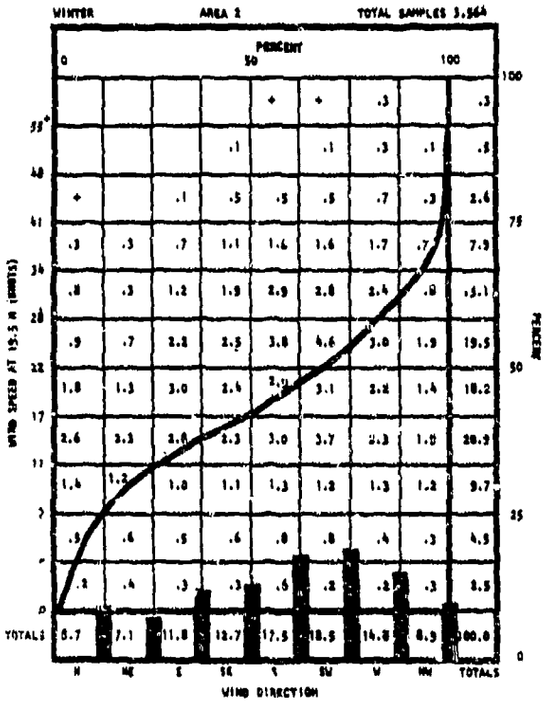


Figure A-2-2-4 Wind Speed by Wind Direction

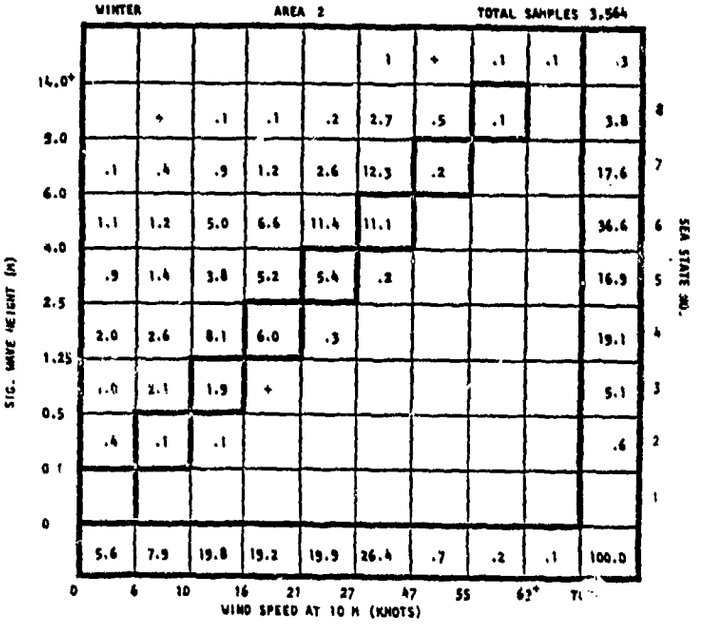


Figure A-2-2-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

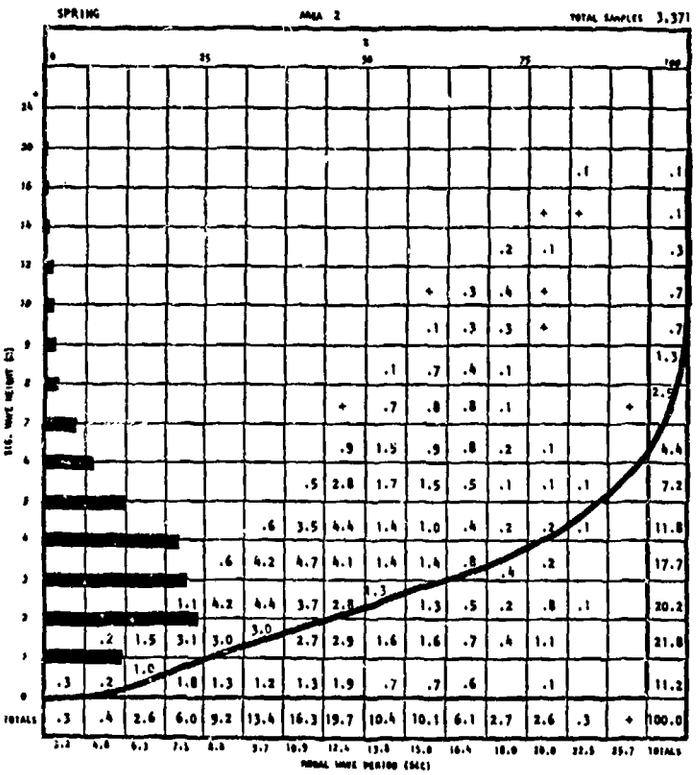


Figure A-2-3-1 Significant Wave Height by Modal Wave Period

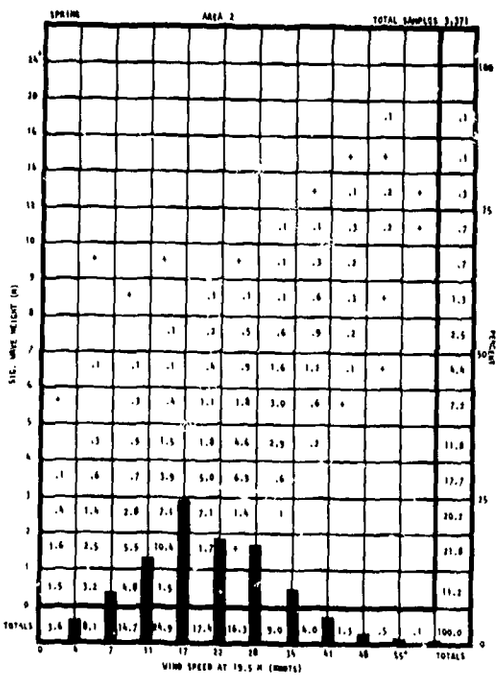


Figure A-2-3-2 Significant Wave Height by Wind Speed

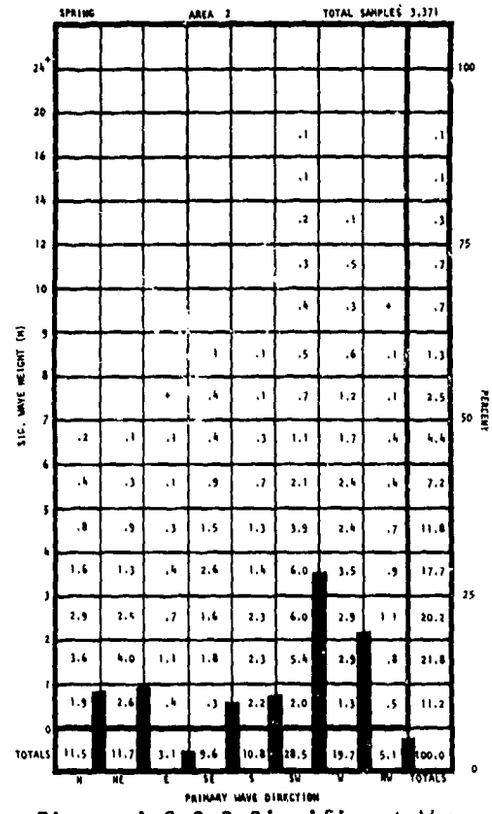


Figure A-2-3-3 Significant Wave Height by Wave Direction

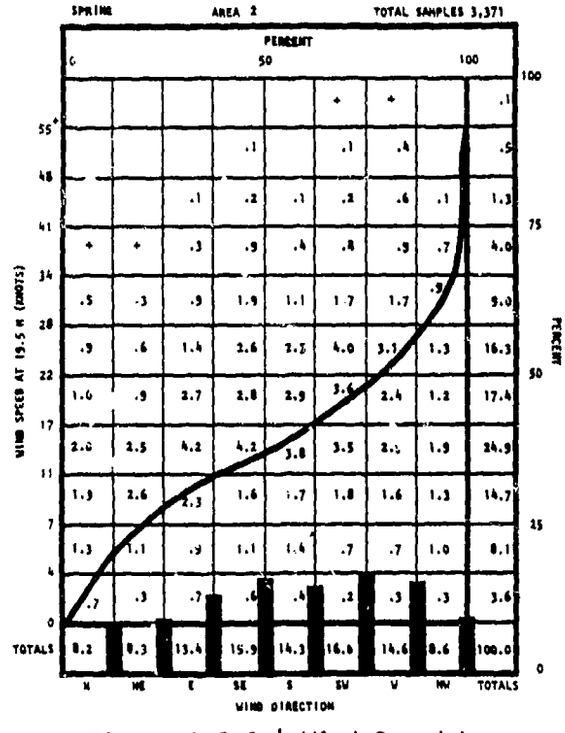


Figure A-2-3-4 Wind Speed by Wind Direction

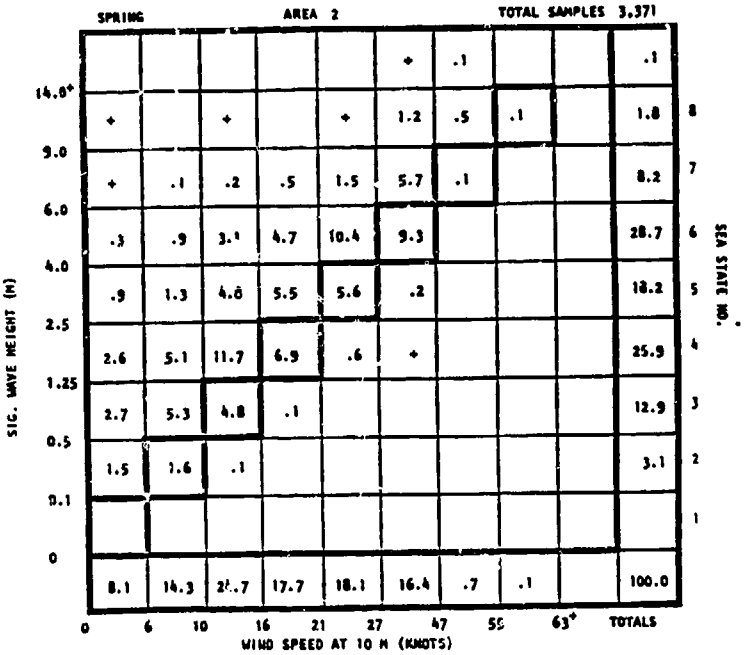


Figure A-2-3-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

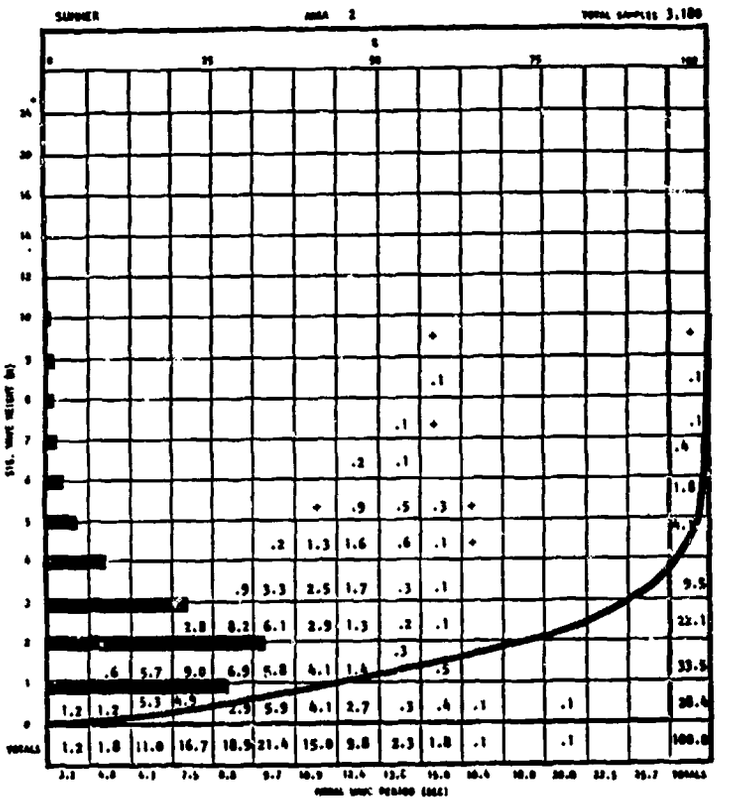


Figure A-2-4-1 Significant Wave Height by Modal Wave Period

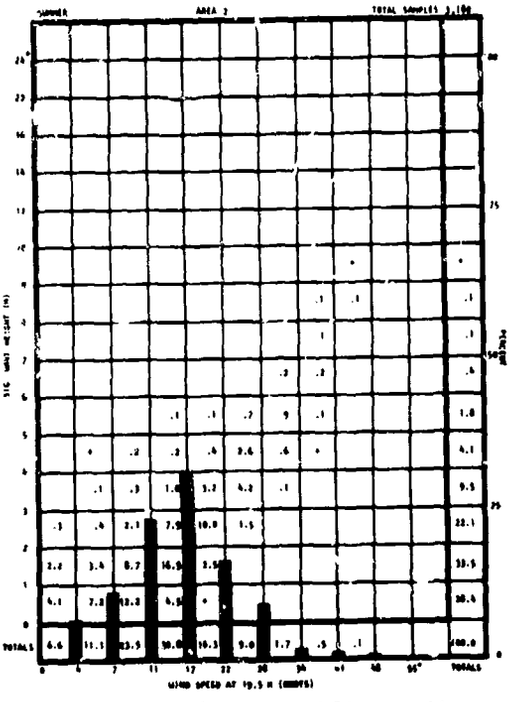


Figure A-2-4-2 Significant Wave Height by Wind Speed

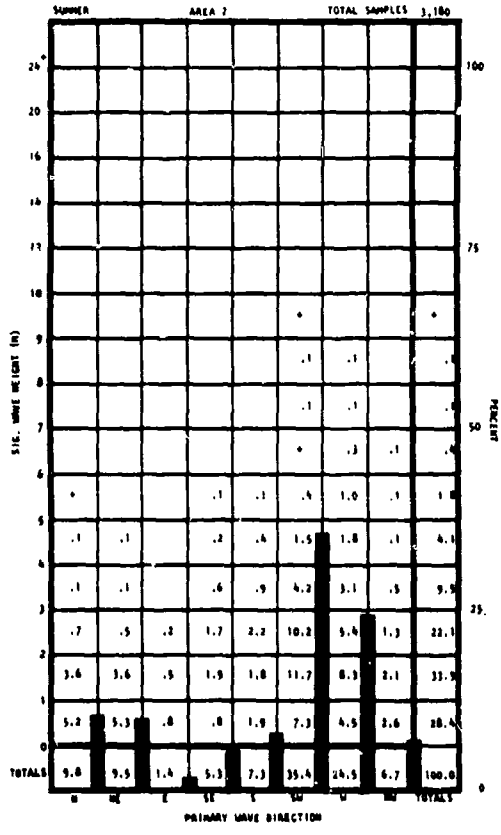


Figure A-2-4-3 Significant Wave Height by Wave Direction

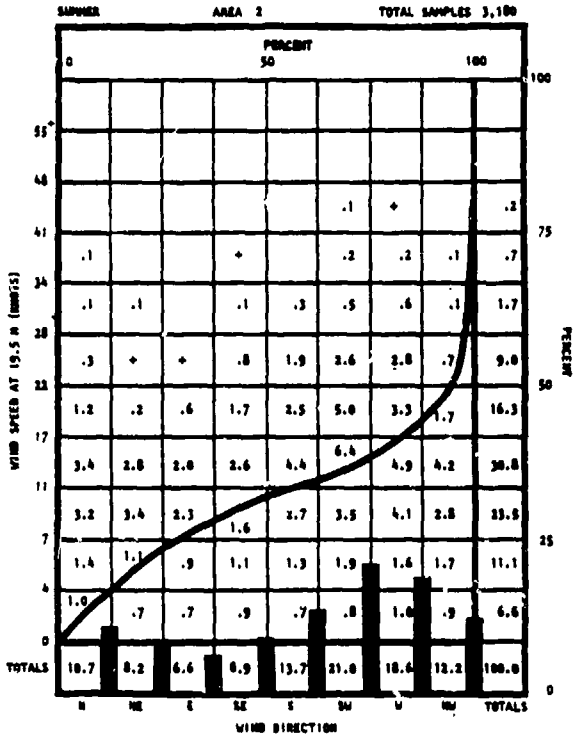


Figure A-2-4-4 Wind Speed by Wind Direction

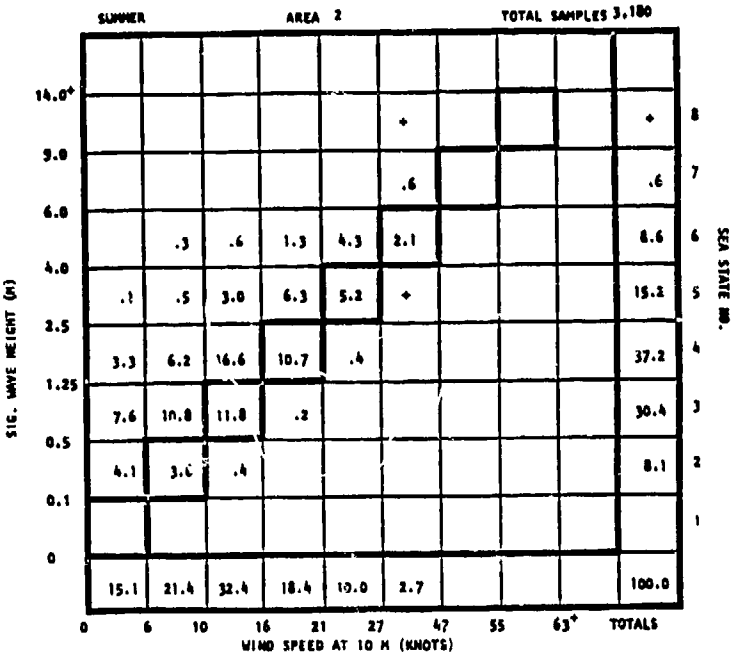


Figure A-2-4-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

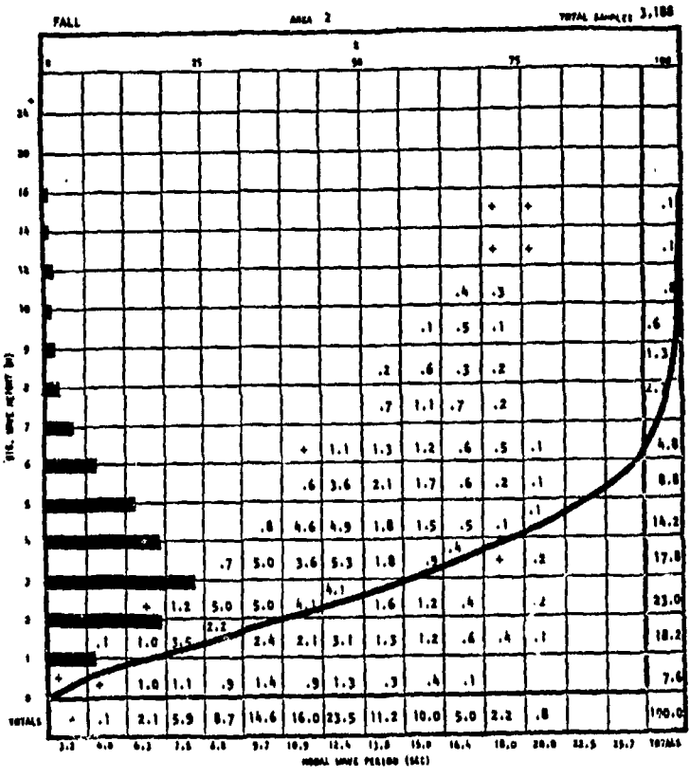


Figure A-2-5-1 Significant Wave Height by Modal Wave Period

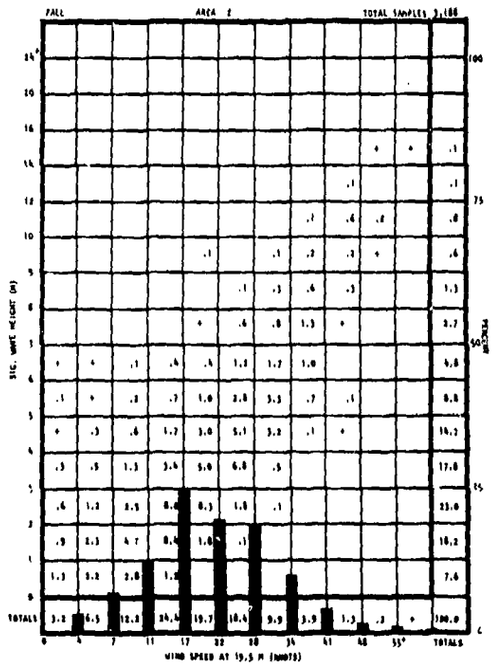


Figure A-2-5-2 Significant Wave Height by Wind Speed

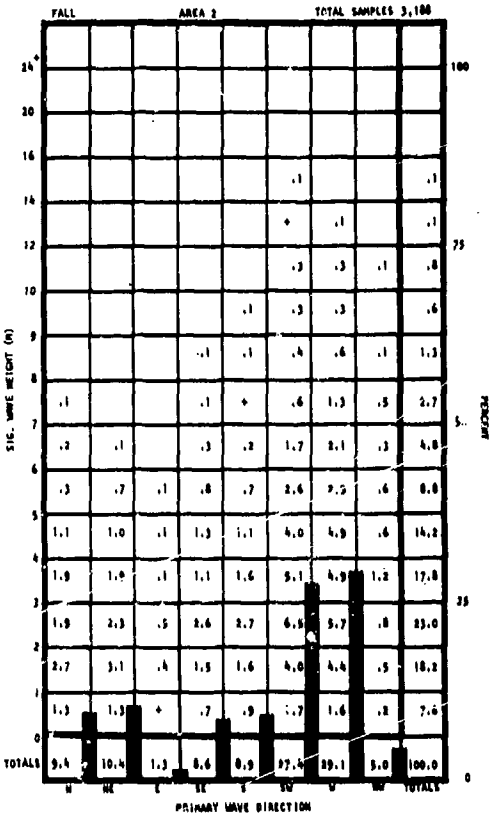


Figure A-2-5-3 Significant Wave Height by Wave Direction

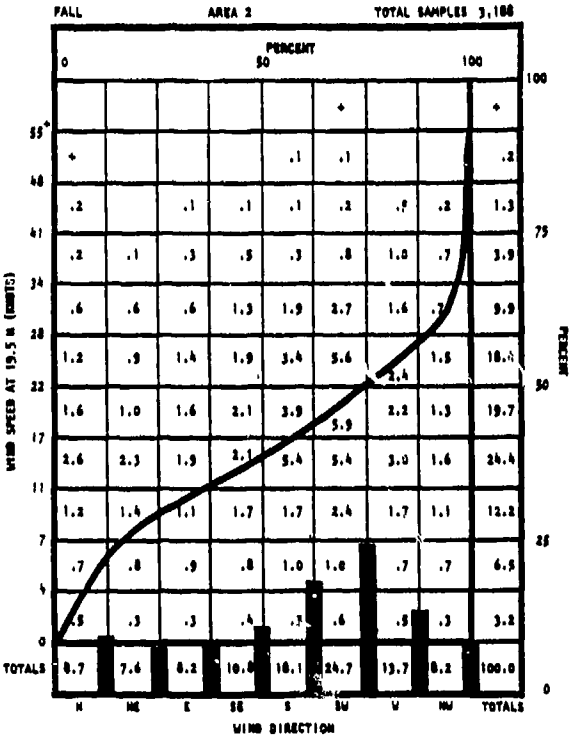


Figure A-2-5-4 Wind Speed by Wind Direction

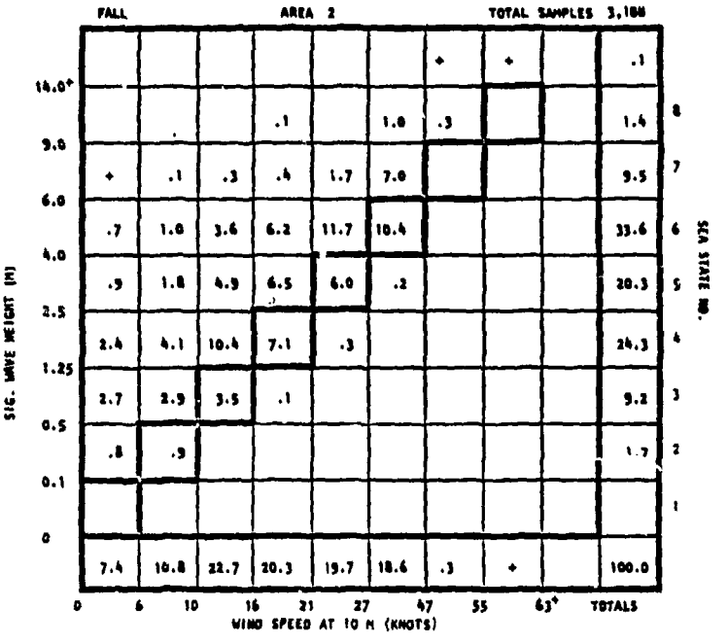


Figure A-2-5-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

TABLE A-6-1-1 - SURFACE NATURAL ENVIRONMENT SUMMARY

Season: Annual; Location: 46.191° N, 44.891° W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface					
Sig. Wave Height, m.	.5	3	7.5	3.5	2
Wave Period, sec	6	10	15.5	10.5	12.5
Direction	-	-	-	-	W
Winds					
Speed, knots	5	16	35	18	14
Corresponding Mean Sig. Wave Height, m.	1.8	2.5	7.5	3	2.5
Direction	-	-	-	-	SW - W - NW
Visibility, nautical miles	1.5	12	25	-	-
Cloud Cover					
Total clouds, in eighths of sky obscured	Nil	6.5	8	-	-
Low clouds, in eighths of sky obscured	Nil	6	8	-	-
Precipitation (Occurrence)	All precipitation - 15% of the time		Snow - 2% of the time (Dec-Mar)		
Relative Humidity, %	65	86	98	-	-
Air Temperature, °C	1.5	10	20	10	-
Surface Water Temperature, °C	3	10.5	21	-	-
Sea Level Pressure, millibars	999	1,016	1,030	-	-
Ice	Moderate superstructure - 1% of the time (Dec -Mar)				
Refractivity					
Mean Surface Refractivity	-	-	-	336	-
Sub-Refraction (1 km, Annual)	-	-	-	-	1% of the time
Super-Refraction or Ducting (1 km, Annual)	-	-	-	-	1% of the time

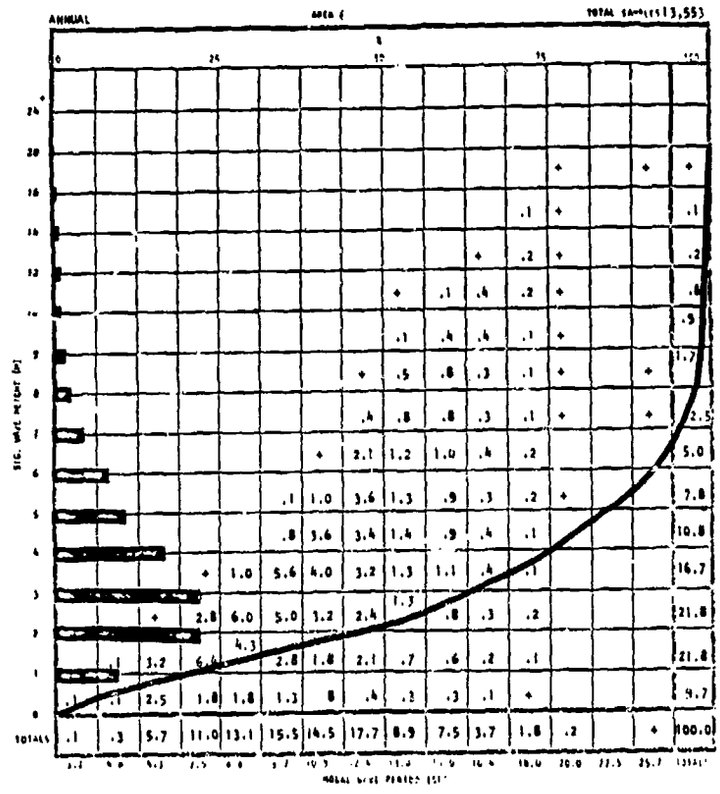


Figure A-6-1-1 Significant Wave Height by Modal Wave Period

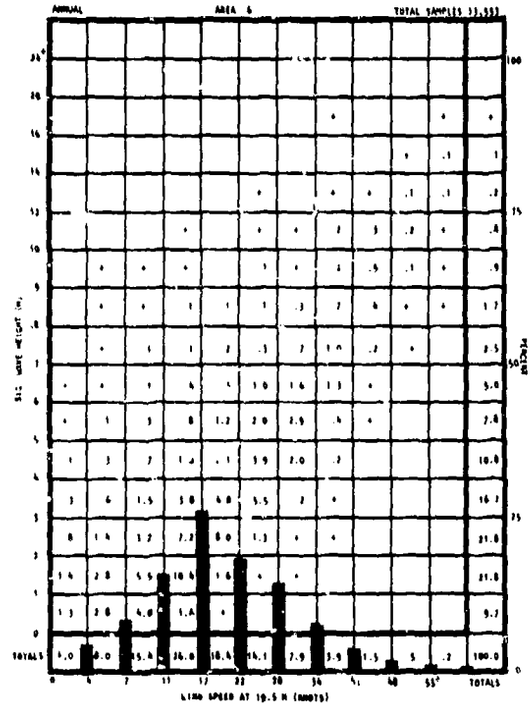


Figure A-6-1-2 Significant Wave Height by Wind Speed

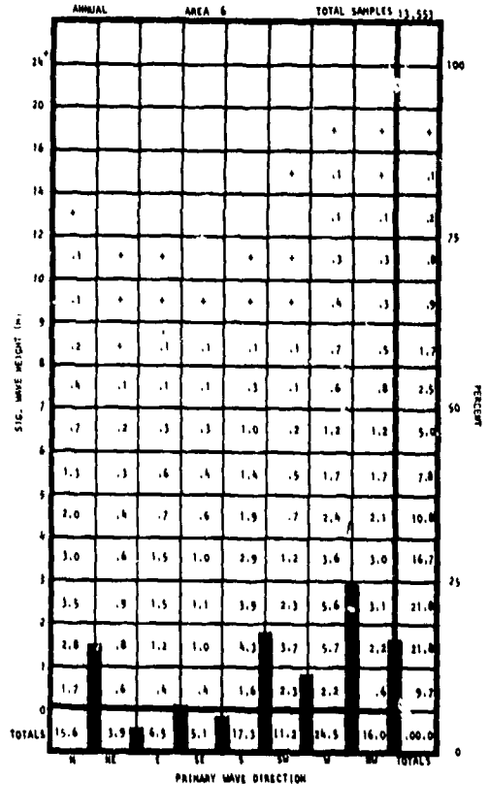


Figure A-6-1-3 Significant Wave Height by Wave Direction

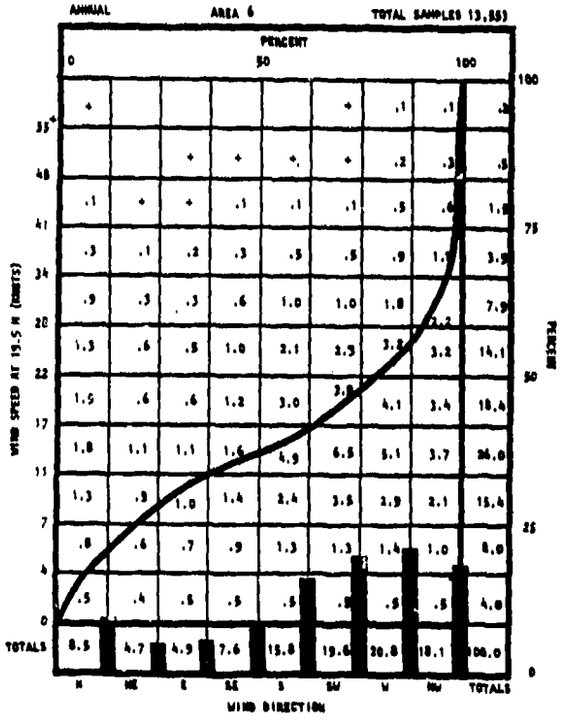


Figure A-6-1-4 Wind Speed by Wind Direction

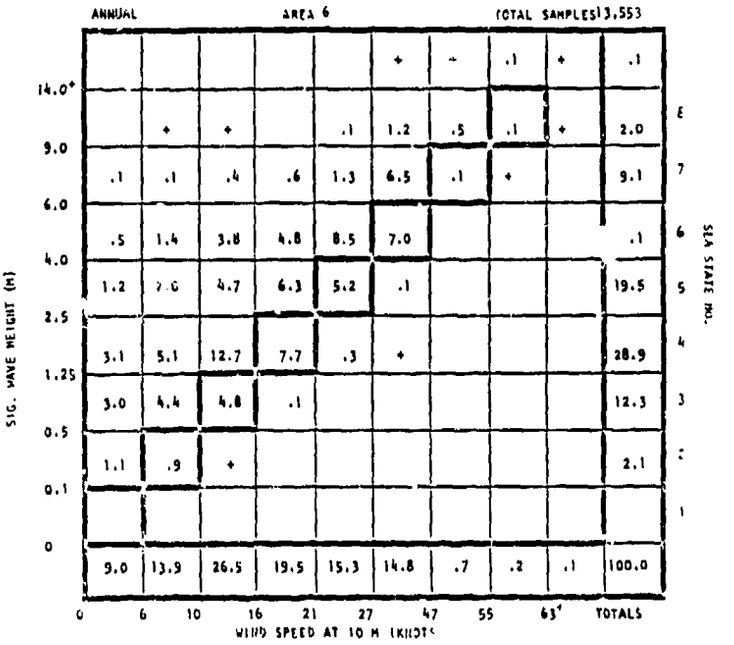


Figure A-6-1-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

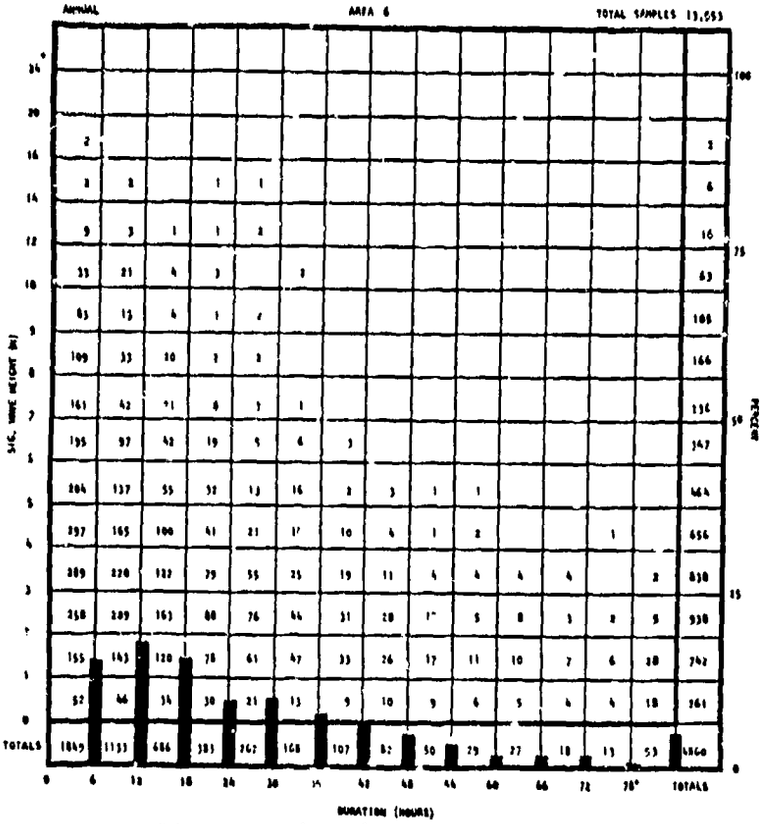


Figure A-6-1-6 Persistence of Significant Wave Height

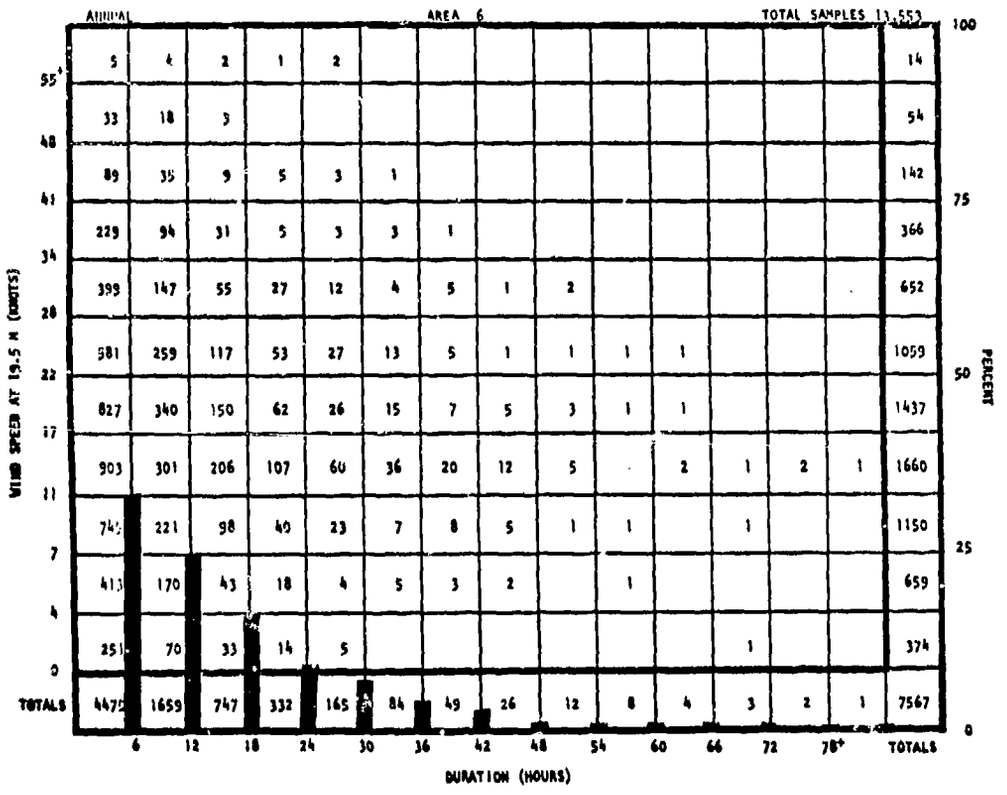


Figure A-6-1-7 Persistence of
Wind Speed

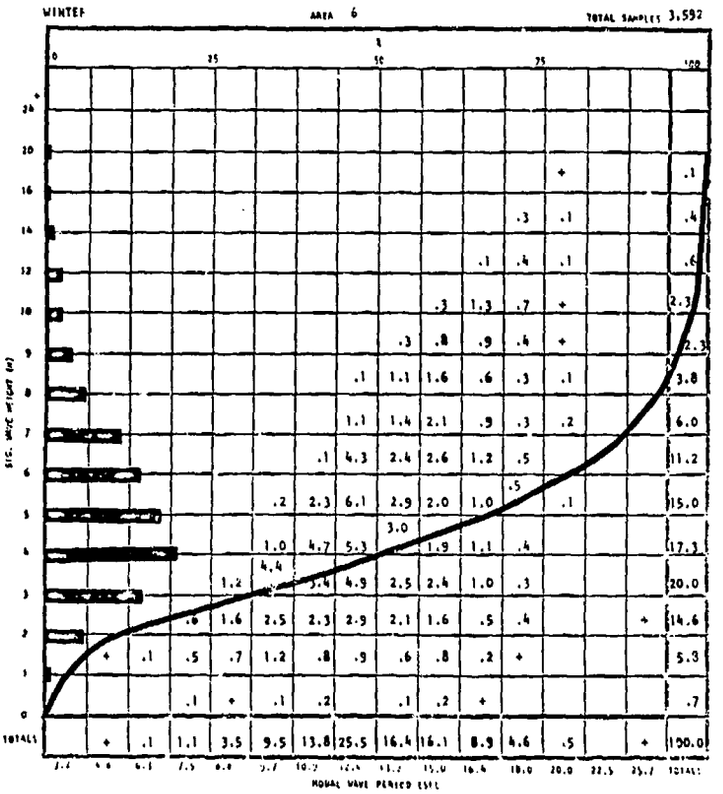


Figure A-6-2-1 Significant Wave Height by Modal Wave Period

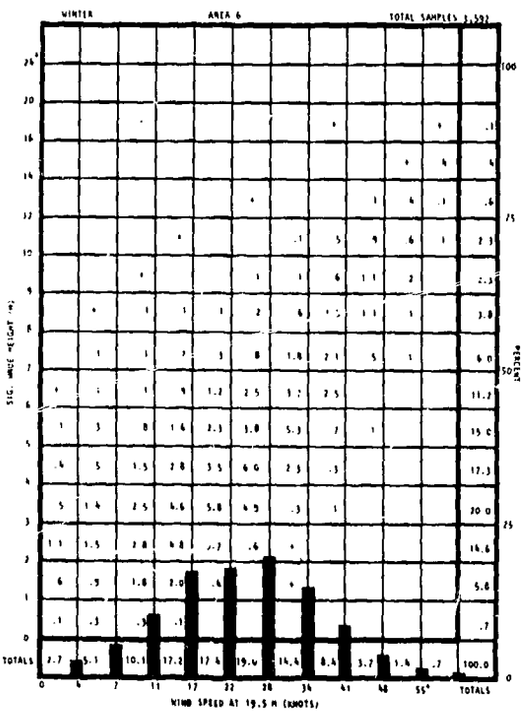


Figure A-6-2-2 Significant Wave Height by Wind Speed

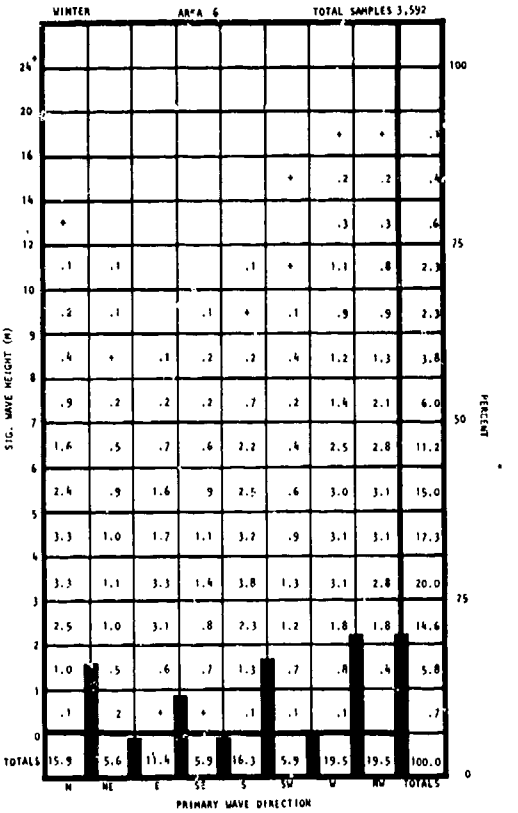


Figure A-6-2-3 Significant Wave Height by Wave Direction

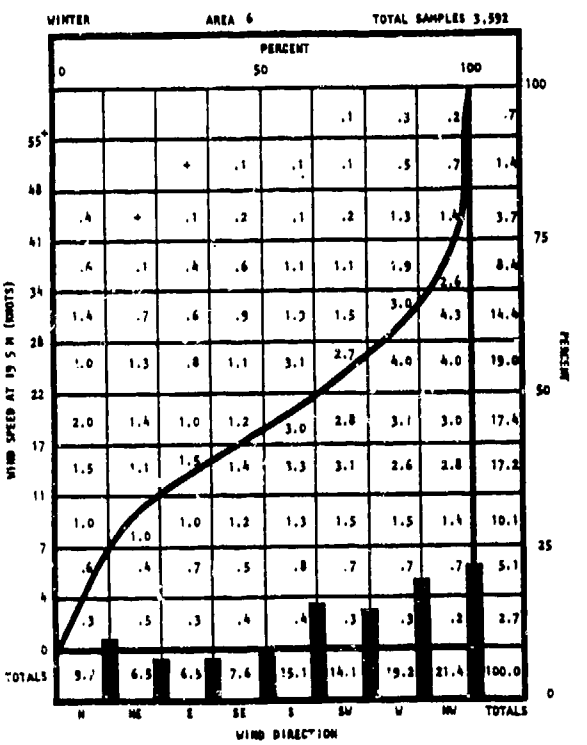


Figure A-6-2-4 Wind Speed by Wind Direction

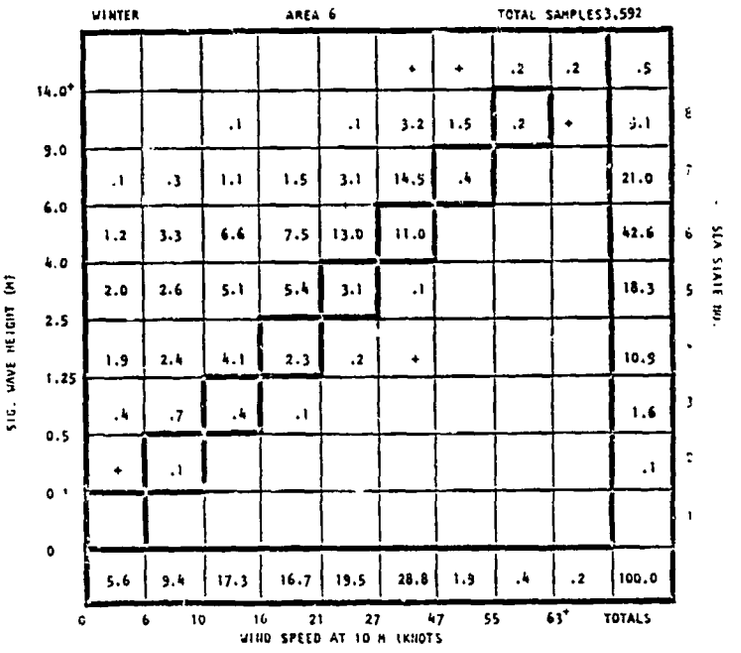


Figure A-6-2-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

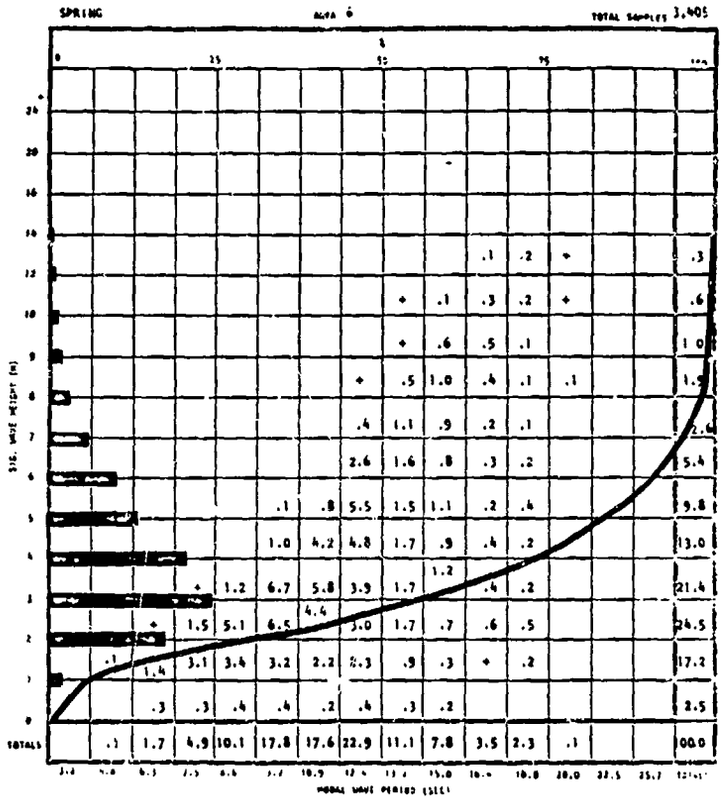


Figure A-6-3-1 Significant Wave Height by Modal Wave Period

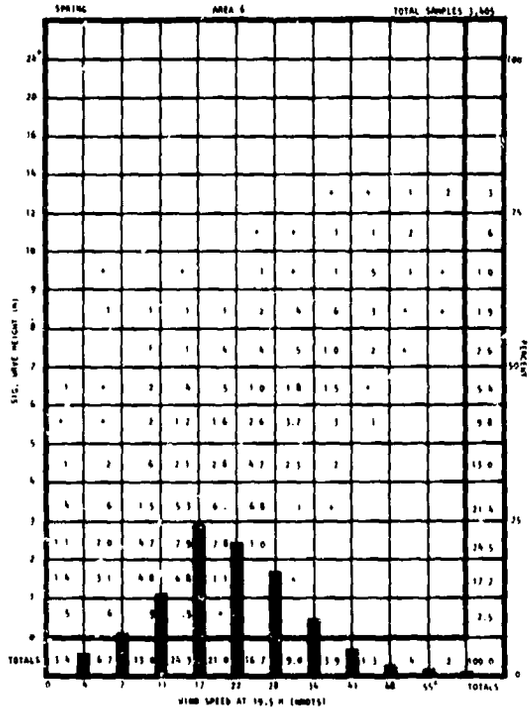


Figure A-6-3-2 Significant Wave Height by Wind Speed

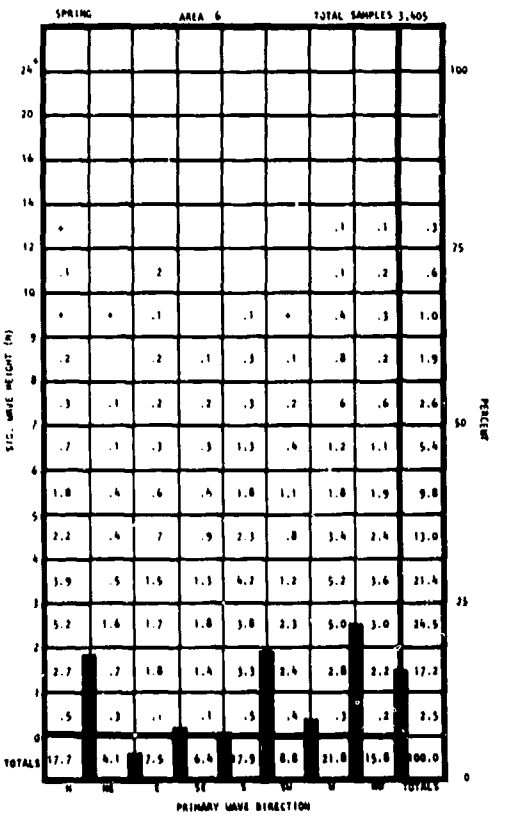


Figure A-6-3-3 Significant Wave Height by Wave Direction

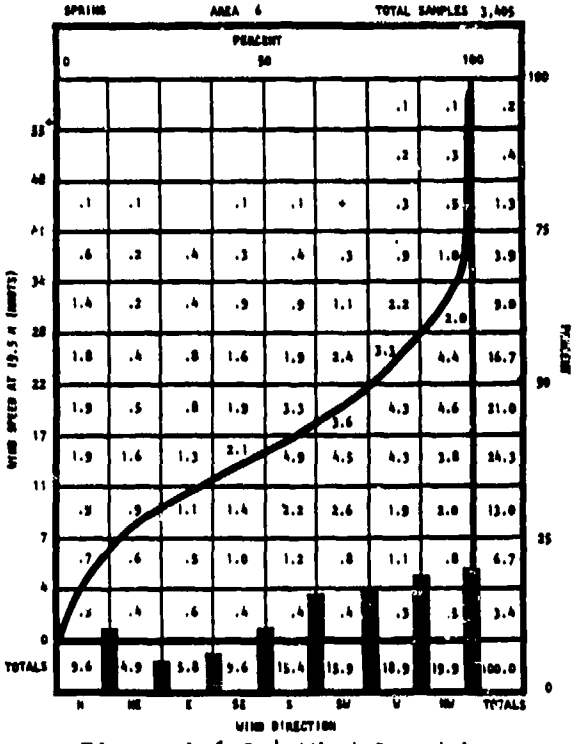


Figure A-6-3-4 Wind Speed by Wind Direction

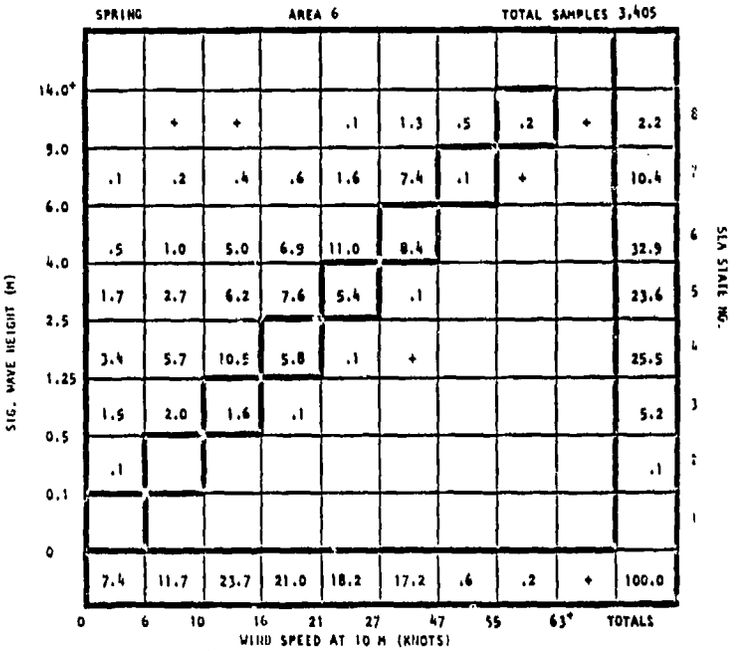


Figure A-6-3-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

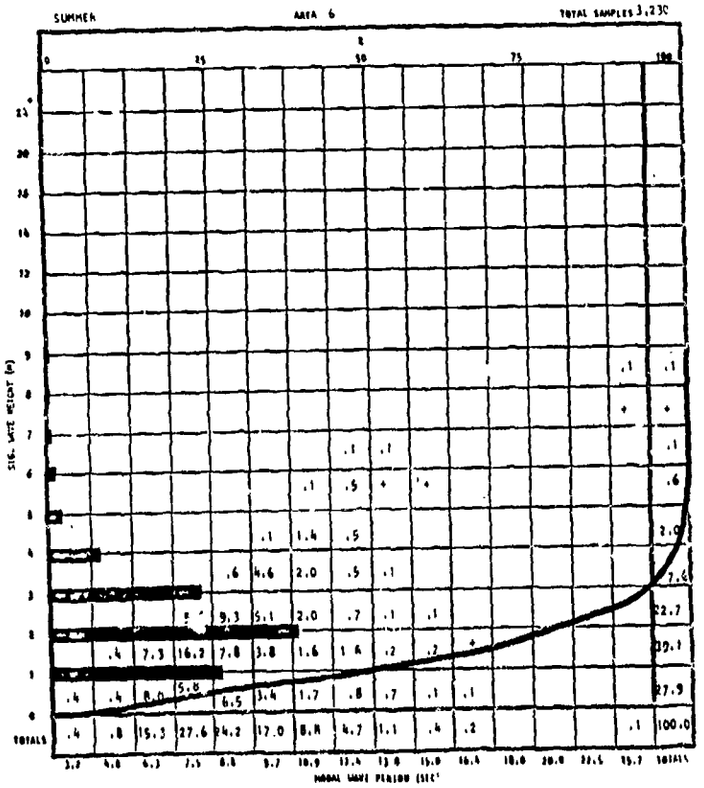


Figure A-6-4-1 Significant Wave Height by Modal Wave Period

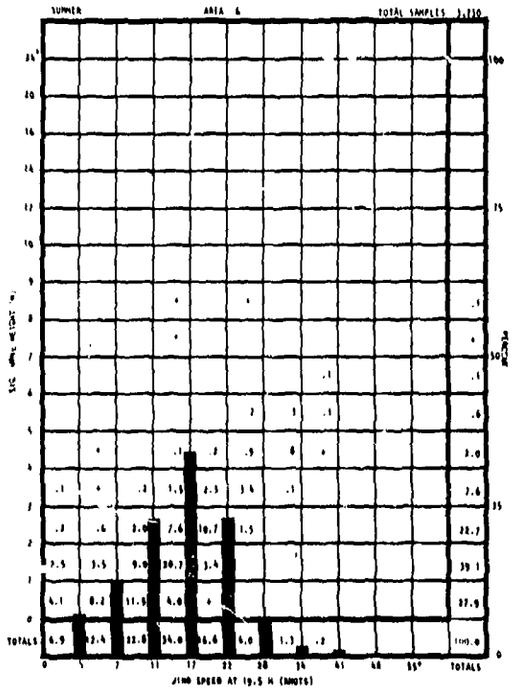


Figure A-6-4-2 Significant Wave Height by Wind Speed

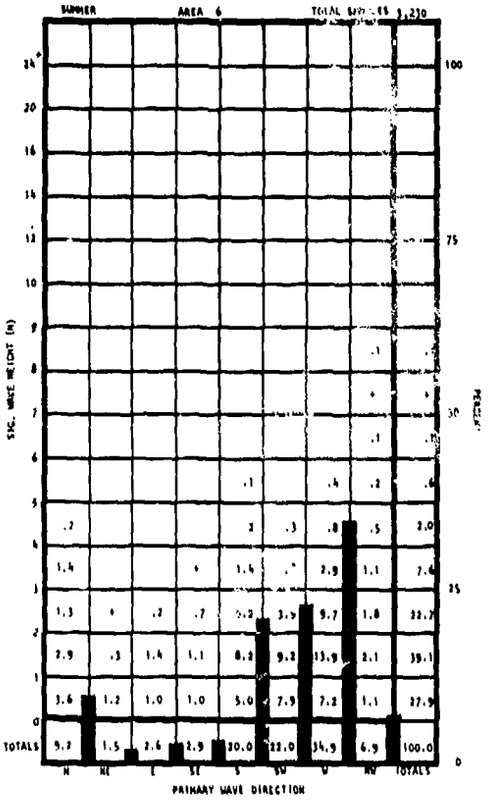


Figure A-6-4-3 Significant Wave Height by Wave Direction

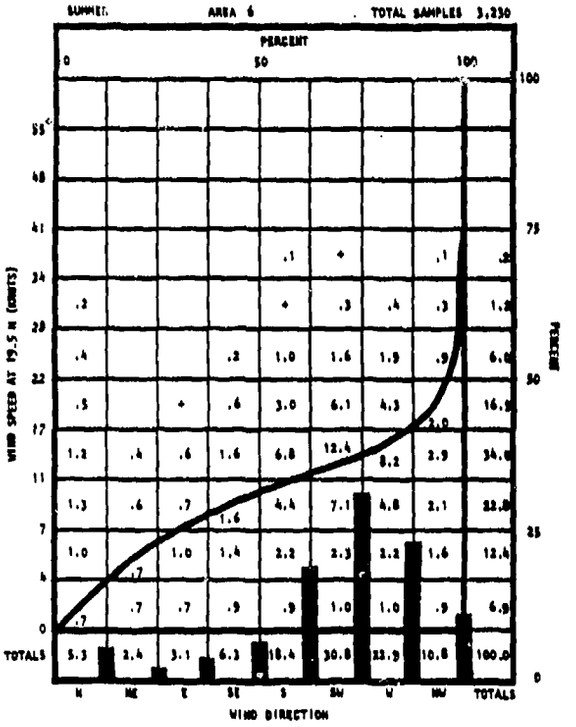


Figure A-6-4-4 Wind Speed by Wind Direction

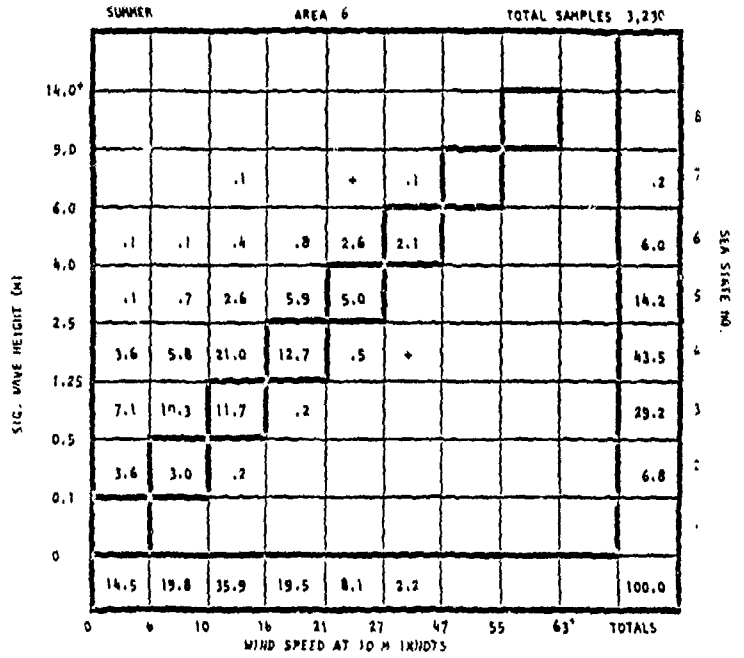


Figure A-6-4-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

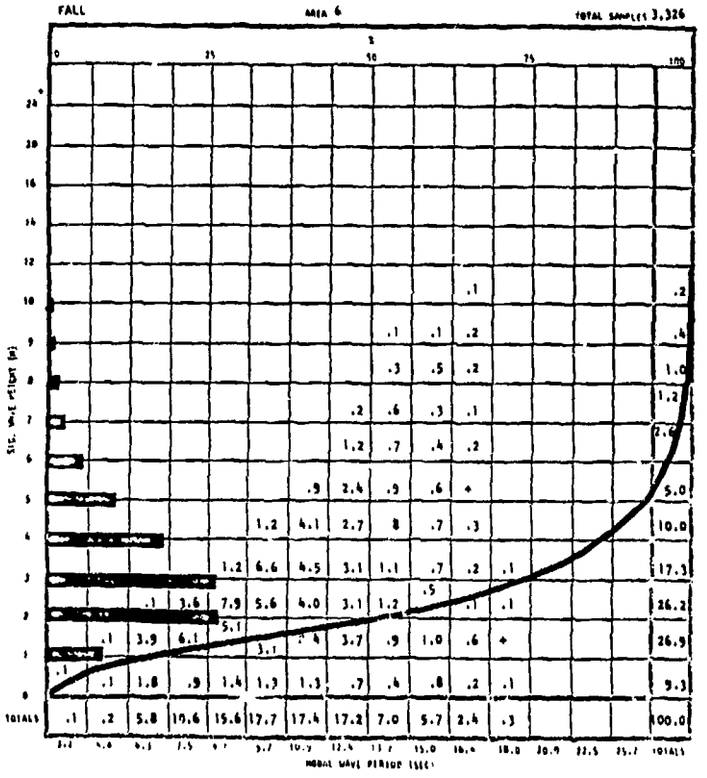


Figure A-6-5-1 Significant Wave Height by Modal Wave Period

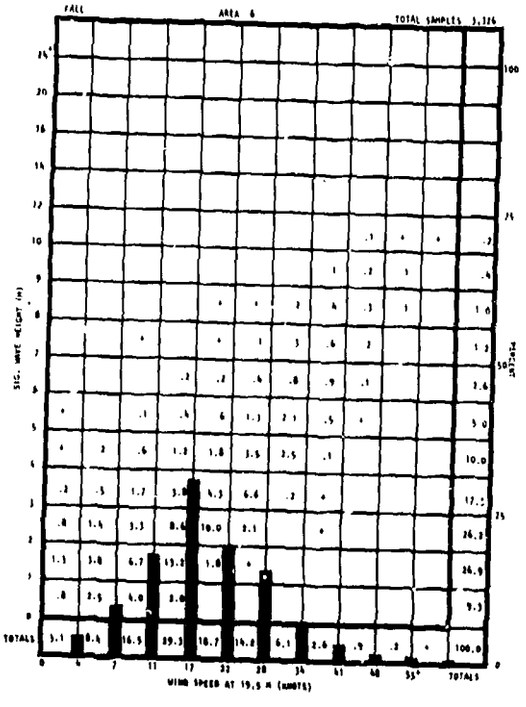


Figure A-6-5-2 Significant Wave Height by Wind Speed

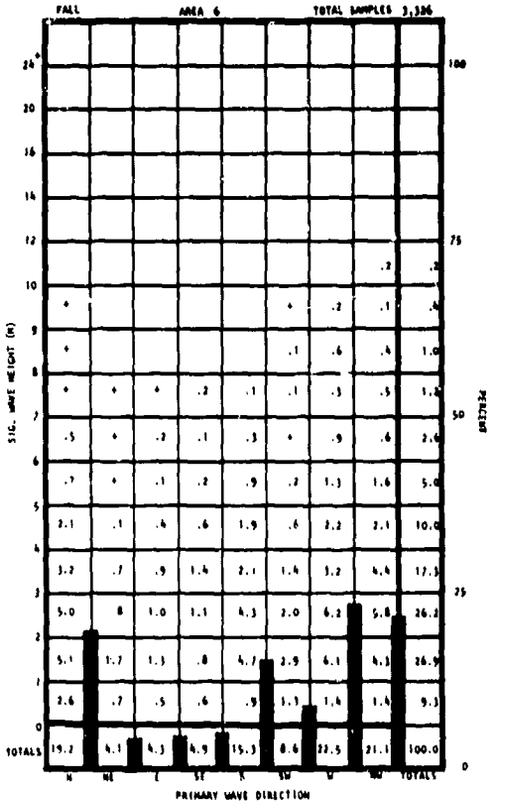


Figure A-6-5-3 Significant Wave Height by Wave Direction

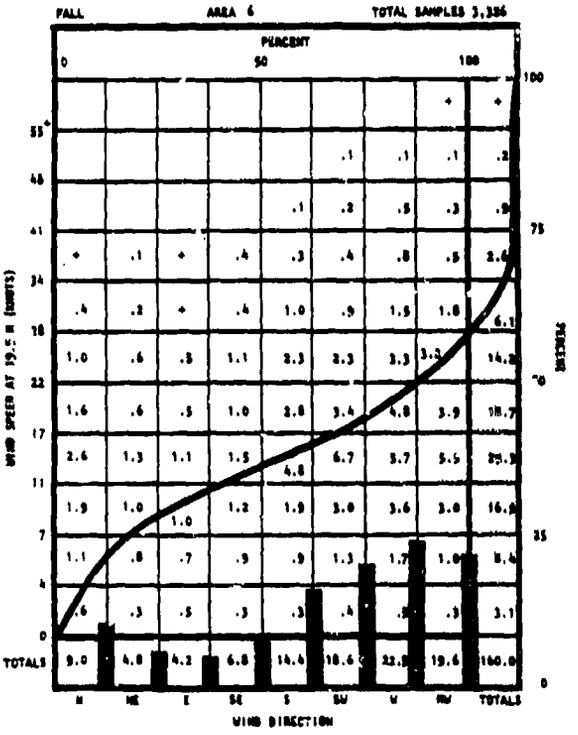


Figure A-6-5-4 Wind Speed by Wind Direction

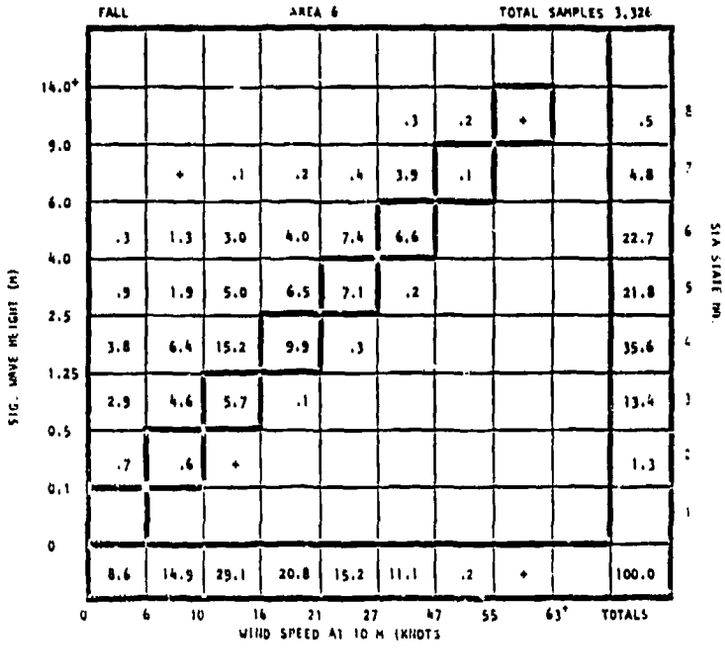


Figure A-6-5-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

TABLE A-7-1-1 - SURFACE NATURAL ENVIRONMENT SUMMARY

Season: Annual; Location: 45.199° N, 21.648° W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface Sig. Wave Height, m. Wave Period, sec Direction	 .5 6 -	 2.5 10 -	 7 16.5 -	 3 10.5 -	 2 12.5 W - NW
Winds Speed, knots Corresponding Mean Sig. Wave Height, m. Direction	 4 1 -	 14 2 -	 33 6 -	 16 2.5 -	 14 2 W - SW
Visibility, nautical miles	2	14	25	-	-
Cloud Cover Total clouds, in eighths of sky obscured Low clouds, in eighths of sky obscured	 Nil Nil	 6 5.5	 8 8	 - -	 - -
Precipitation (Occurrence)	All precipitation - 16% of the time		Snow - 1% of the time (Dec - Mar)		
Relative Humidity, %	61	82	97	-	-
Air Temperature, °C	9	13.5	18.5	13.5	-
Surface Water Temperature, °C	11	13.5	18.5	-	-
Sea Level Pressure, millibars	994	1,014	1,032	-	-
Ice	None				
Refractivity Mean Surface Refractivity Sub-Refraction (1 km, Annual) Super-Refraction or Ducting (1 km, Annual)	 - - -	 - - -	 - - -	 335 - -	 - 4% of the time 2% of the time

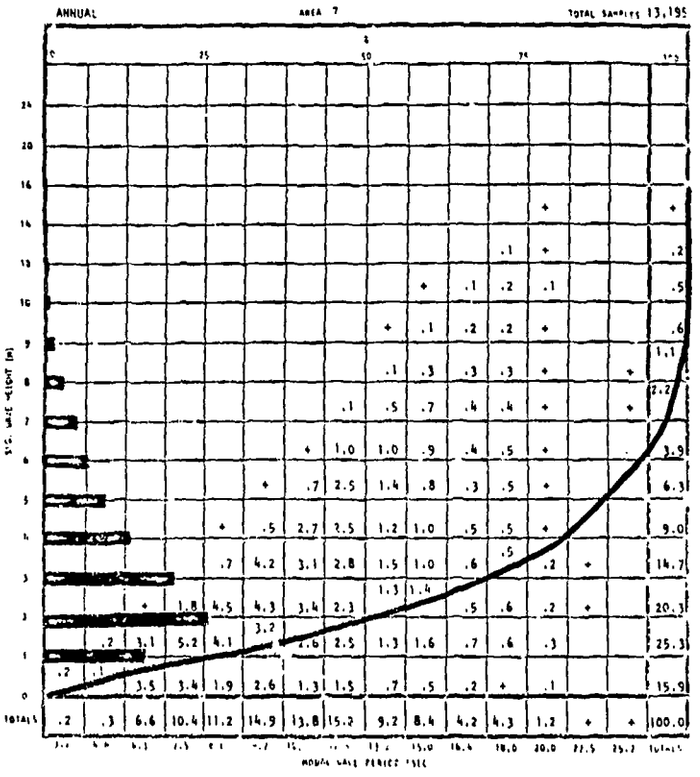


Figure A-7-1-1 Significant Wave Height by Modal Wave Period

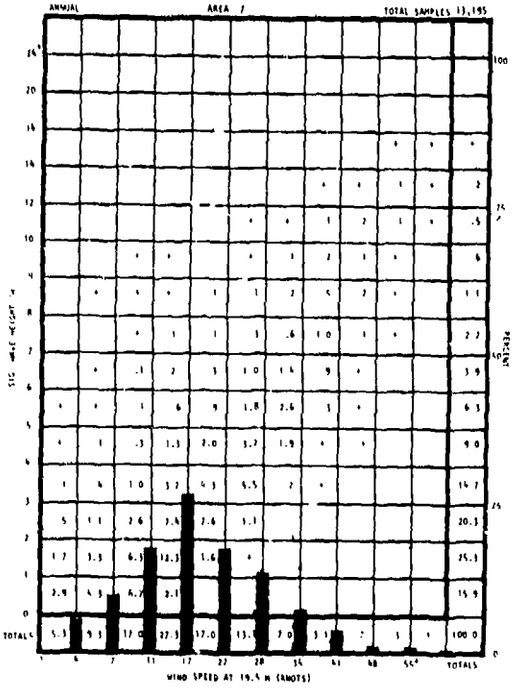


Figure A-7-1-2 Significant Wave Height by Wind Speed

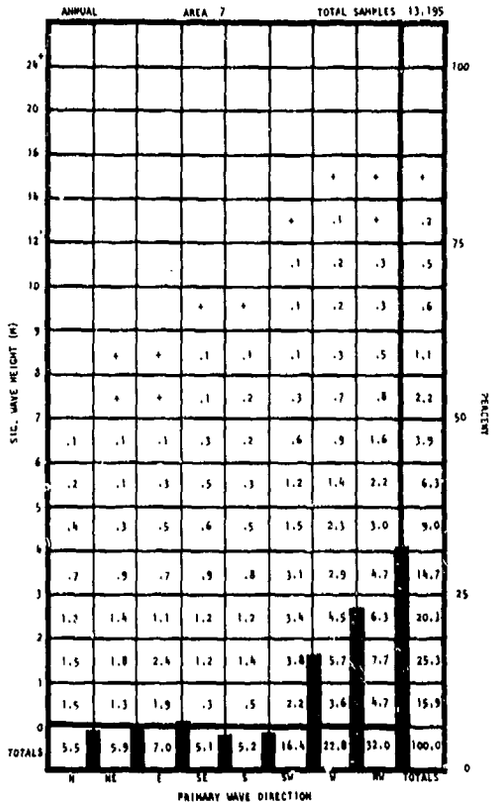


Figure A-7-1-3 Significant Wave Height by Wave Direction

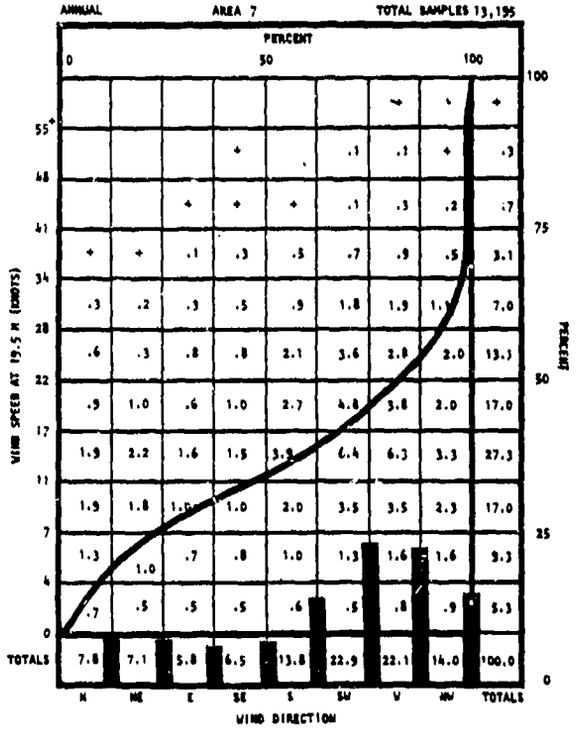


Figure A-7-1-4 Wind Speed by Wind Direction

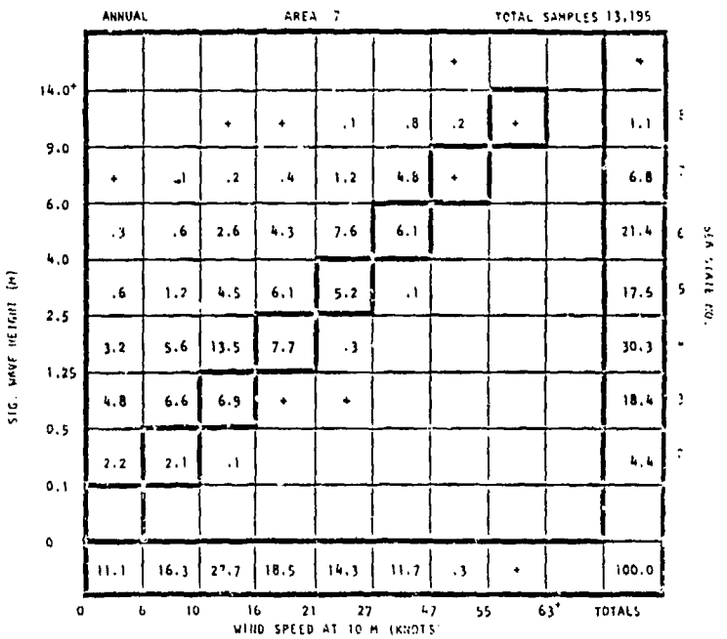


Figure A-7-1-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

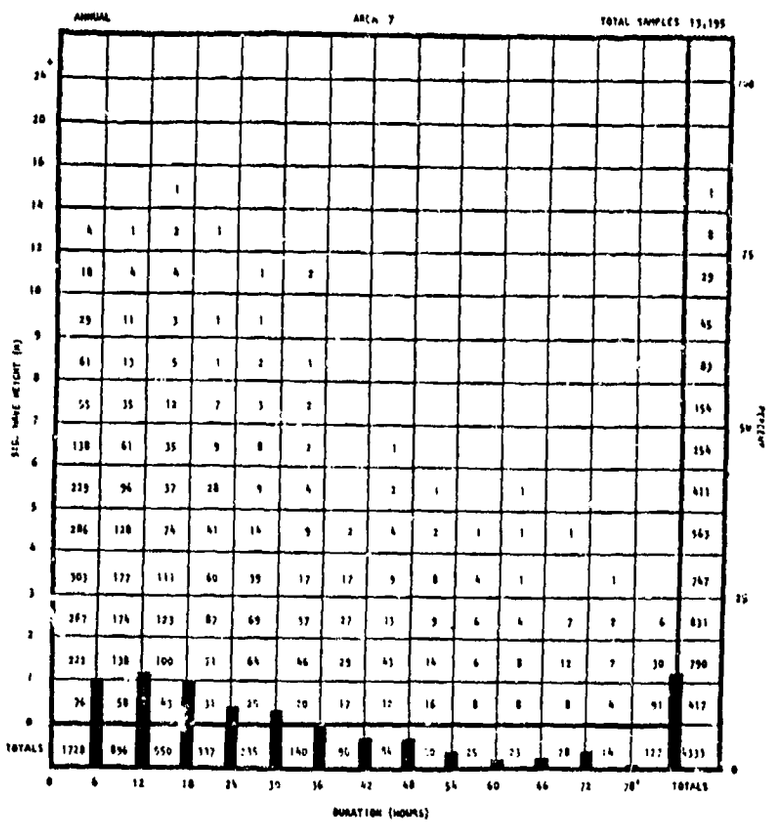


Figure A-7-1-6 Persistence of Significant Wave Height

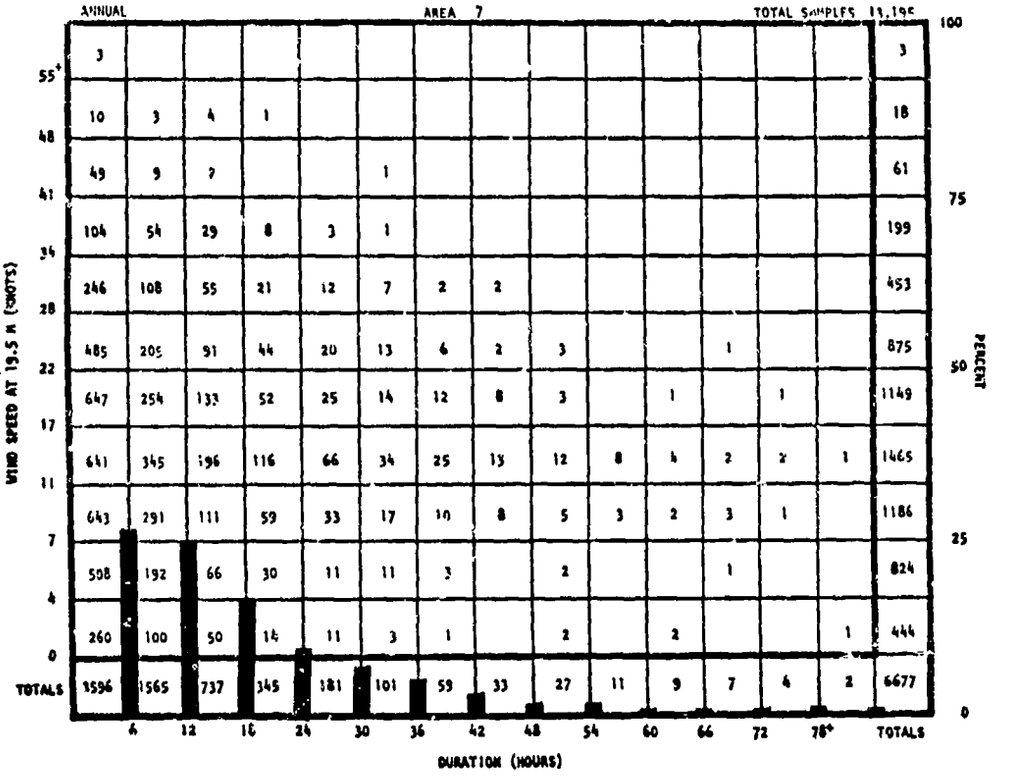


Figure A-7-1-7 Persistence of
Wind Speed

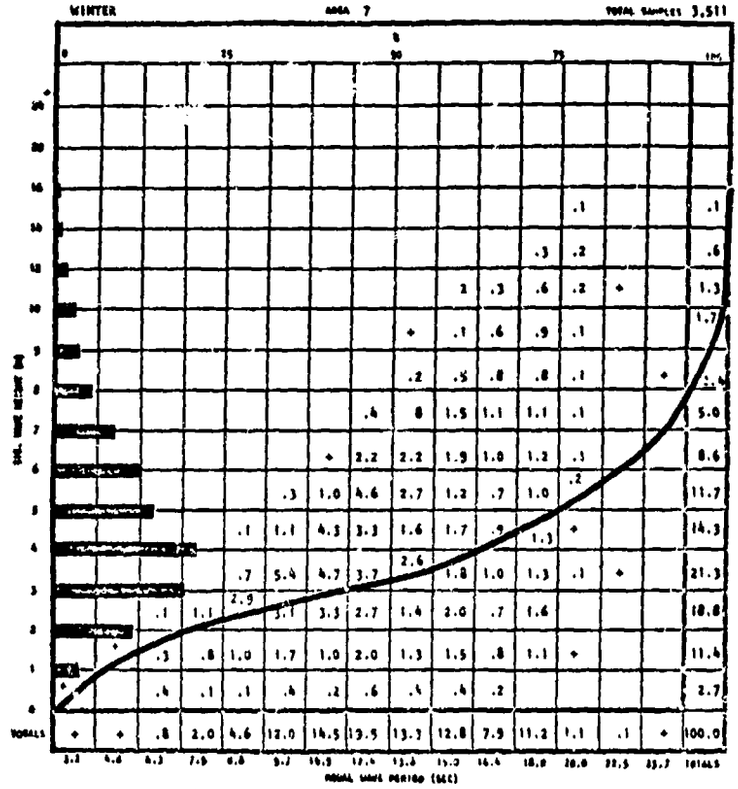


Figure A-7-2-1 Significant Wave Height by Modal Wave Period

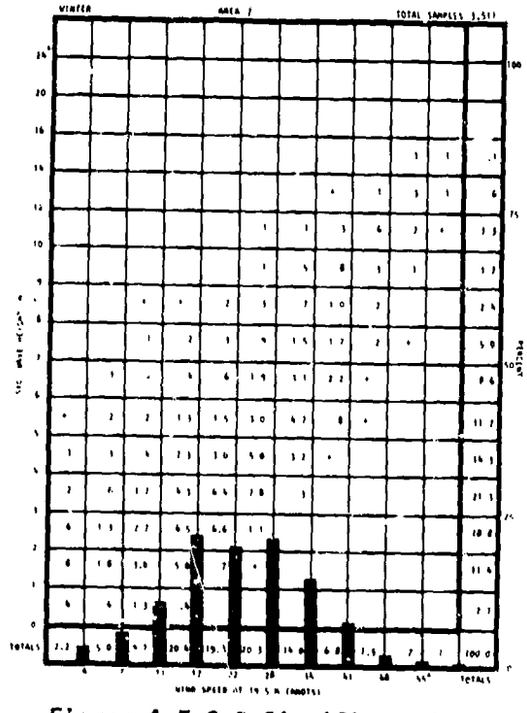


Figure A-7-2-2 Significant Wave Height by Wind Speed

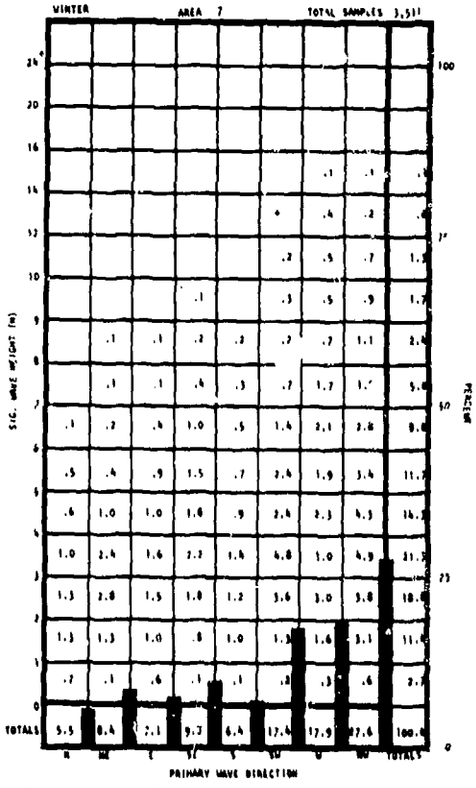


Figure A-7-2-3 Significant Wave Height by Wave Direction

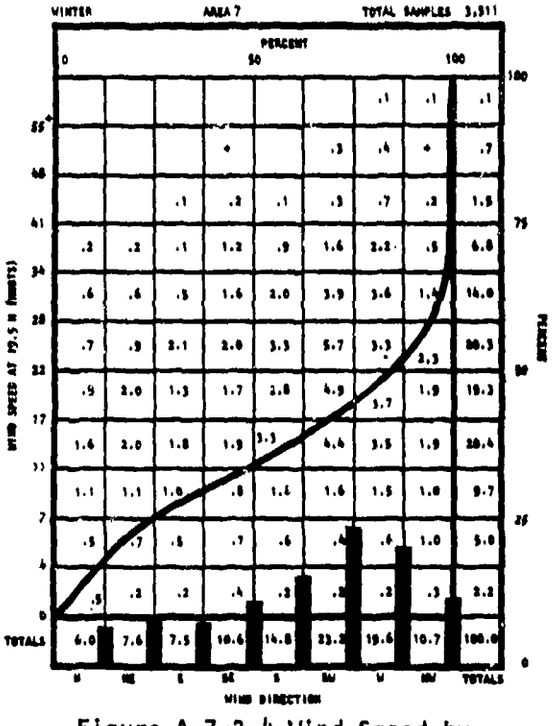


Figure A-7-2-4 Wind Speed by Wind Direction

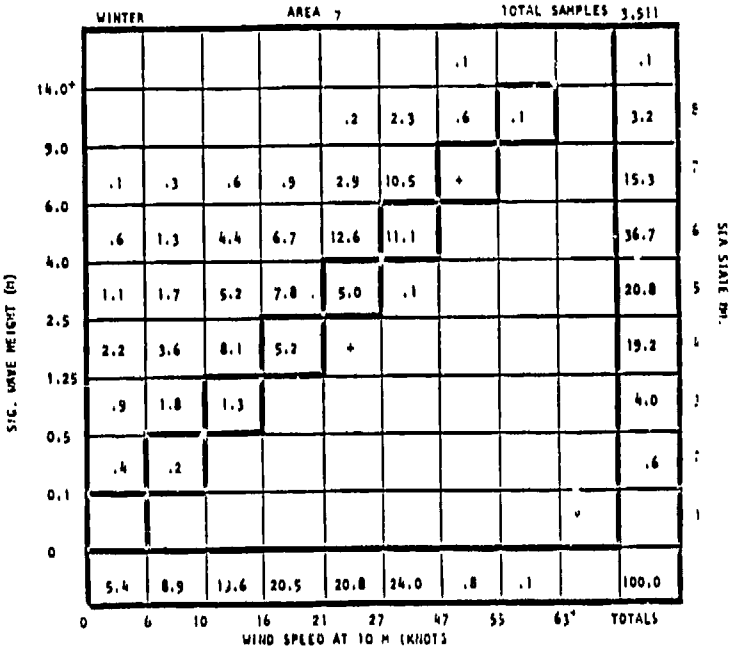


Figure A-7-2-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

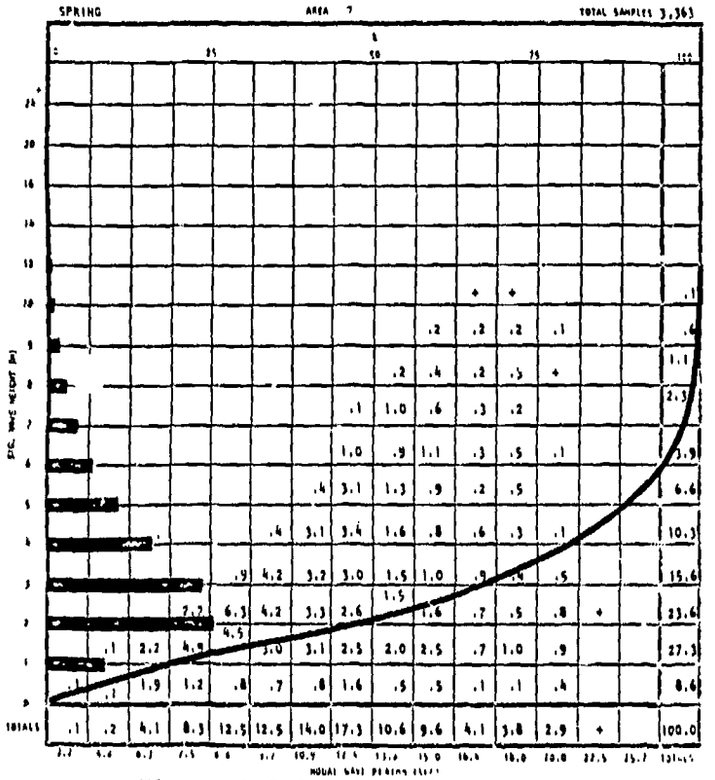


Figure A-7-3-1 Significant Wave Height by Modal Wave Period

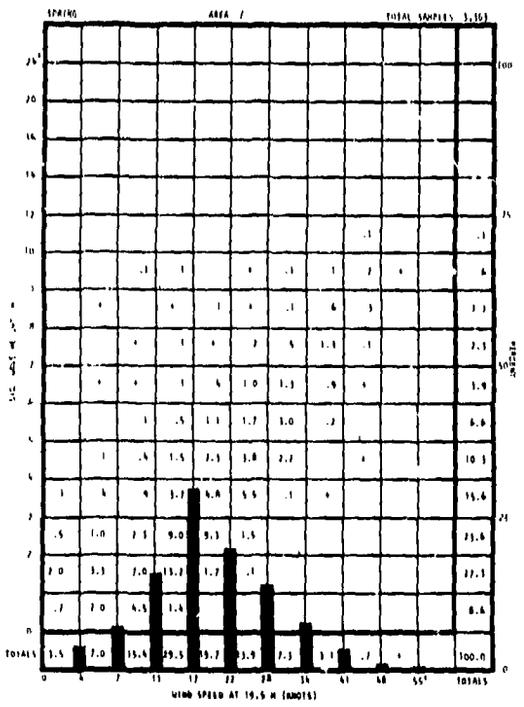


Figure A-7-3-2 Significant Wave Height by Wind Speed

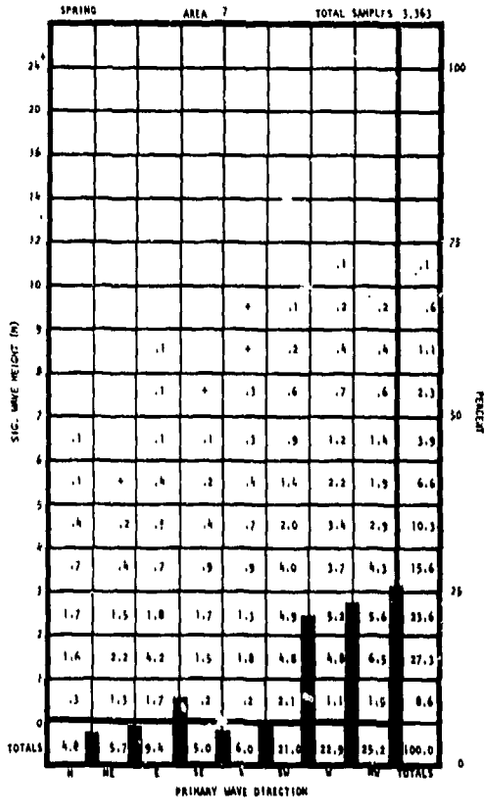


Figure A-7-3-3 Significant Wave Height by Wave Direction

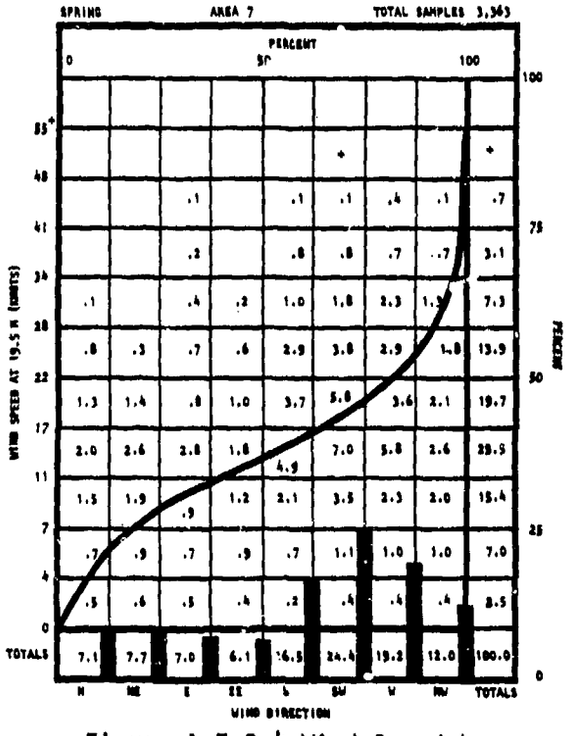


Figure A-7-3-4 Wind Speed by Wind Direction

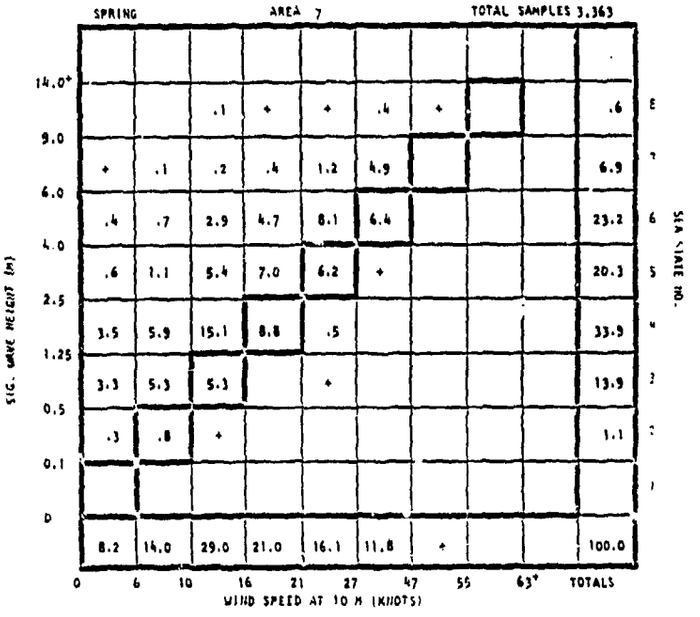


Figure A-7-3-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

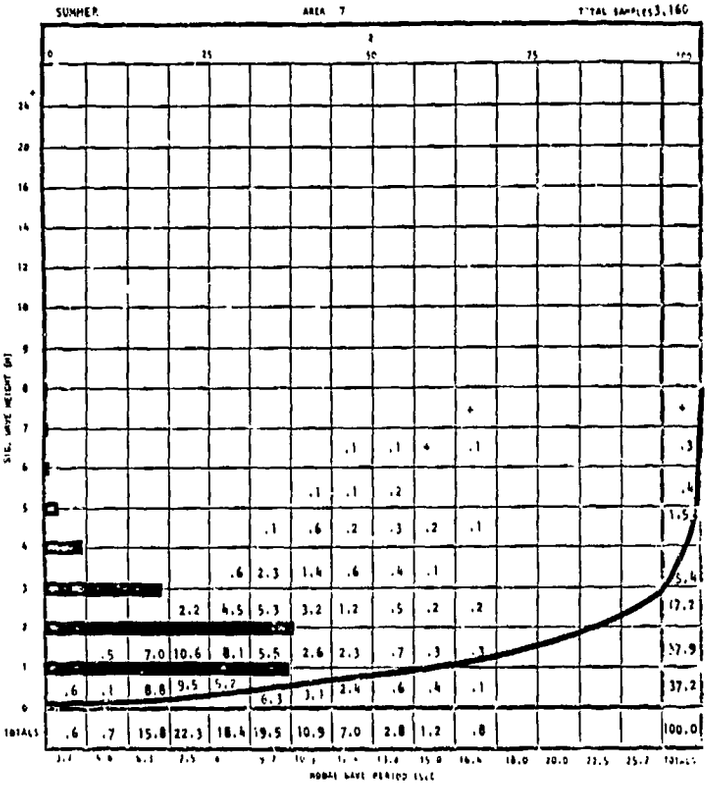


Figure A-7-4-1 Significant Wave Height by Modal Wave Period

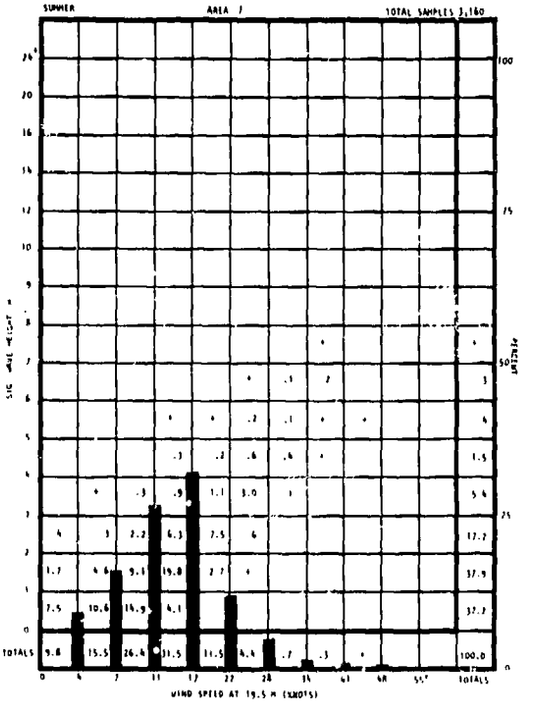


Figure A-7-4-2 Significant Wave Height by Wind Speed

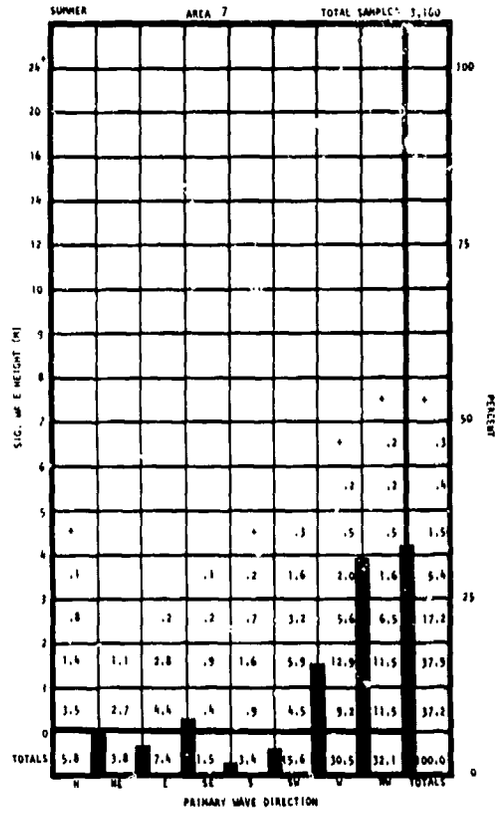


Figure A-7-4-3 Significant Wave Height by Wave Direction

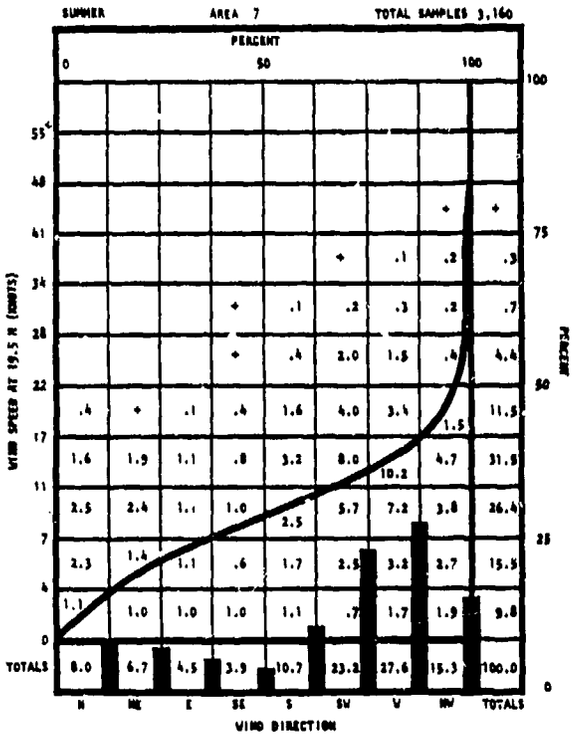


Figure A-7-4-4 Wind Speed by Wind Direction

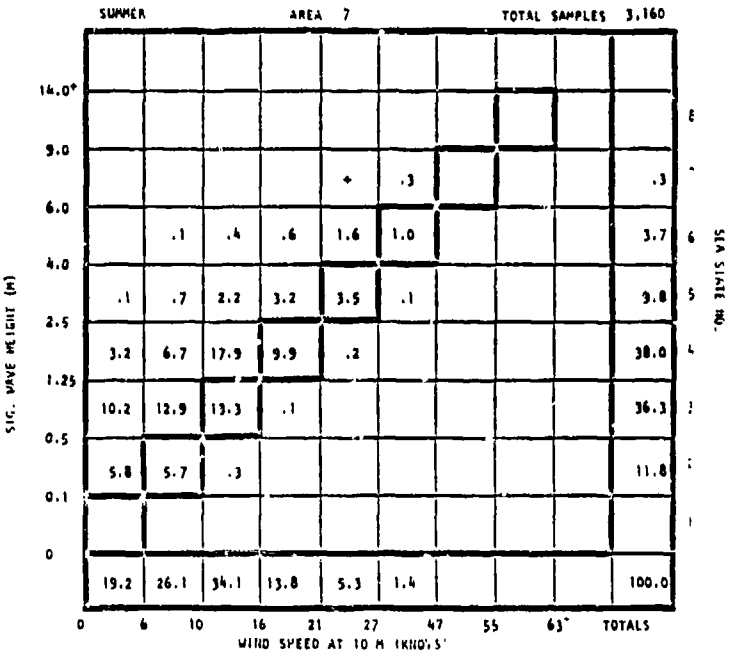


Figure A-7-4-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

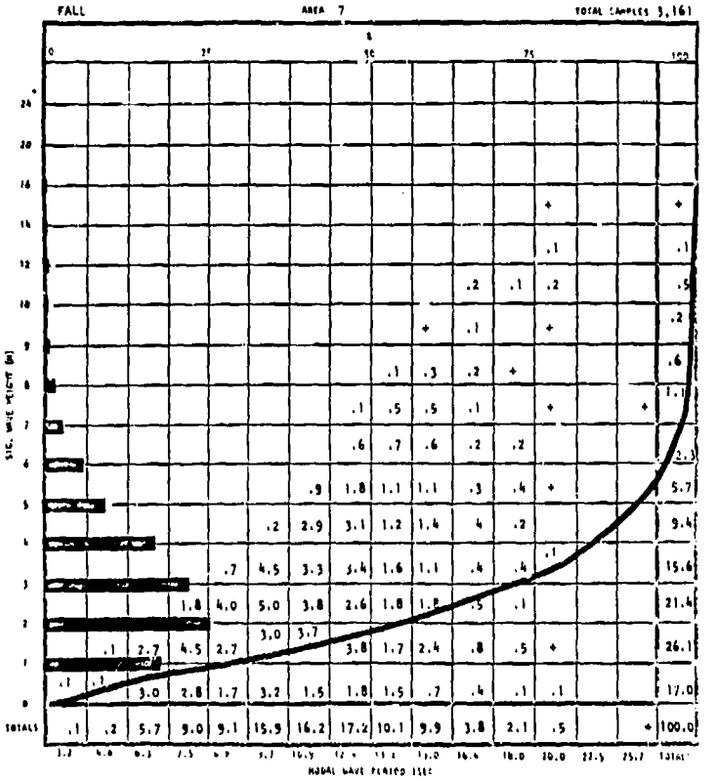


Figure A-7-5-1 Significant Wave Height by Modal Wave Period

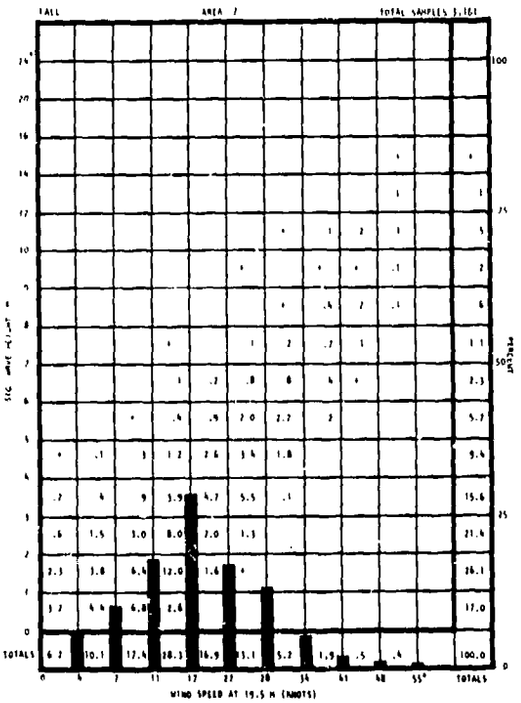


Figure A-7-5-2 Significant Wave Height by Wind Speed

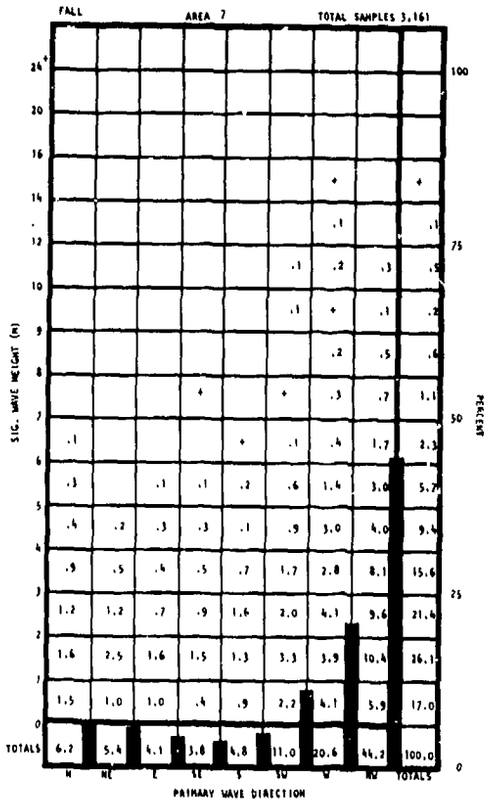


Figure A-7-5-3 Significant Wave Height by Wave Direction

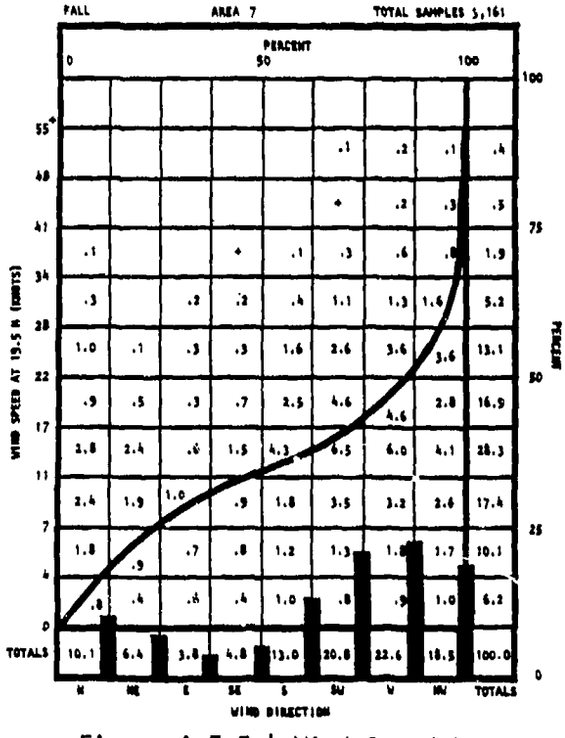


Figure A-7-5-4 Wind Speed by Wind Direction

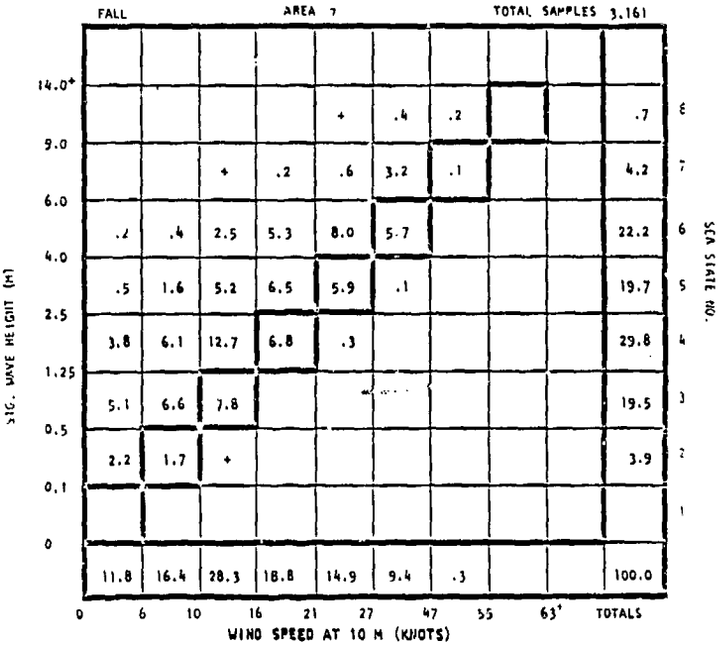


Figure A-7-5-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

TABLE A-10-1-1 - SURFACE NATURAL ENVIRONMENT SUMMARY

Season: Annual; Location: 34.097° N, 52.857° W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface Sig. Wave Height, m. Wave Period, sec Direction	.5 5 -	1.5 9 -	5.5 16 -	2 10 -	1 9.5 W
Winds Speed, knots Corresponding Mean Sig. Wave Height, m. Direction	2 1 -	11 1.5 -	28 5 -	13 2 -	12 1.5 SW
Visibility, nautical miles	6	13	24	-	-
Cloud Cover Total clouds, in eighths of sky obscured Low clouds, in eighths of sky obscured	1 1	6 3.5	8 7.5	- -	- -
Precipitation (Occurrence)	All precipitation - 14% of the time				
Relative Humidity, %	57	76	96	-	-
Air Temperature, °C	15.5	20.5	26	20.5	-
Surface Water Temperature, °C	17.5	21	26	-	-
Sea Level Pressure, millibars	1,007	1,020	1,029	-	-
Ice	None				
Refractivity Mean Surface Refractivity Sub-Refraction (1 km, Annual) Super-Refraction or Ducting (1 km, Annual)	- - -	- - -	- - -	353 - -	- 1% of the time 2% of the time

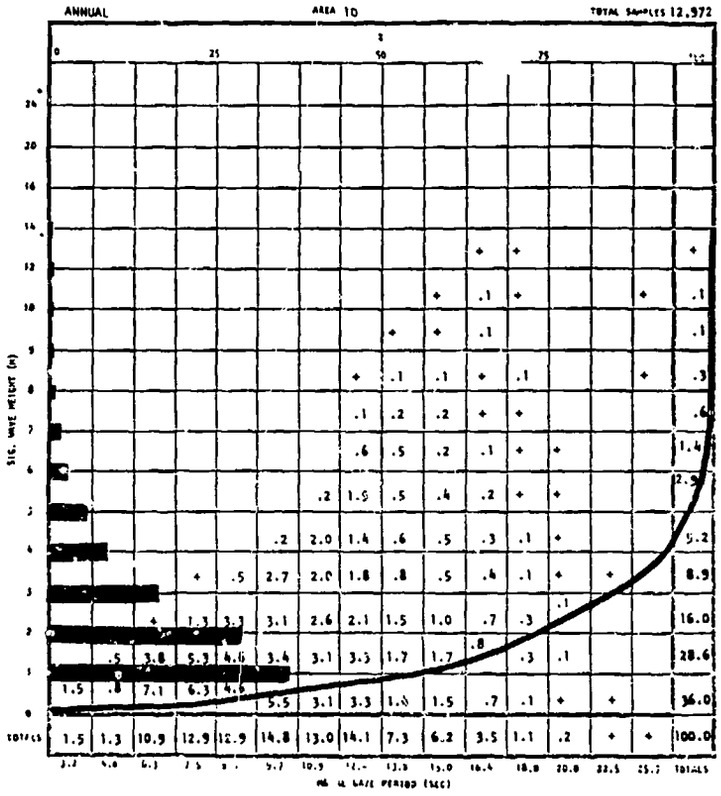


Figure A-10-1-1 Significant Wave Height by Modal Wave Period

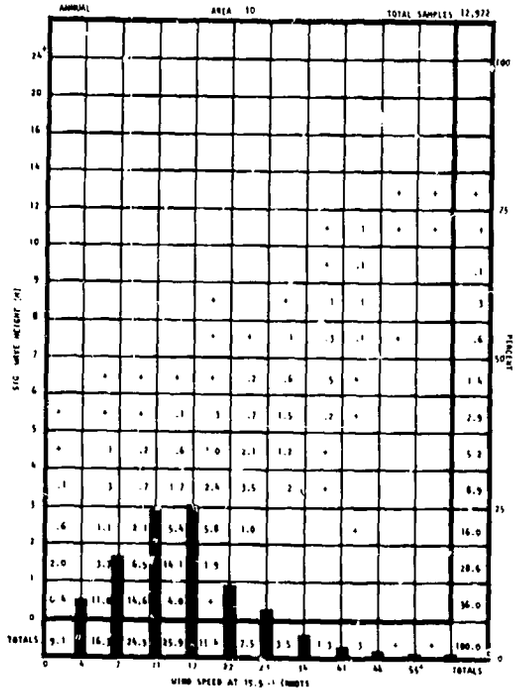


Figure A-10-1-2 Significant Wave Height by Wind Speed

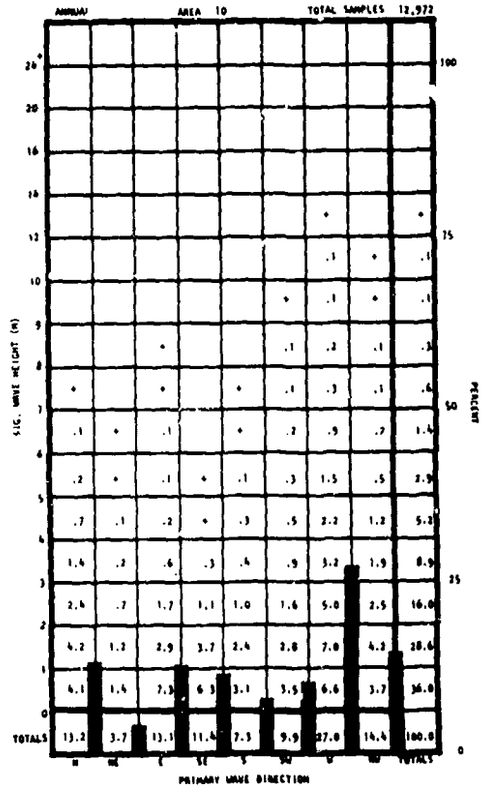


Figure A-10-1-3 Significant Wave Height by Wave Direction

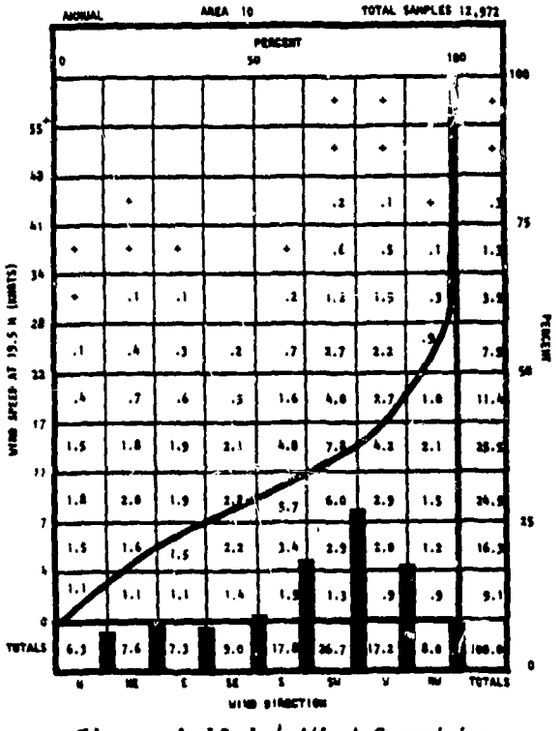


Figure A-10-1-4 Wind Speed by Wind Direction

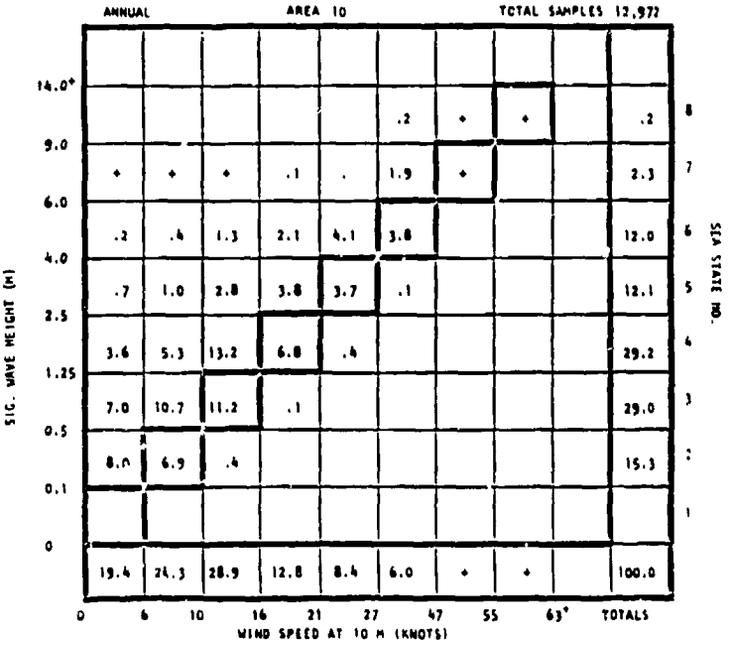


Figure A-10-1-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

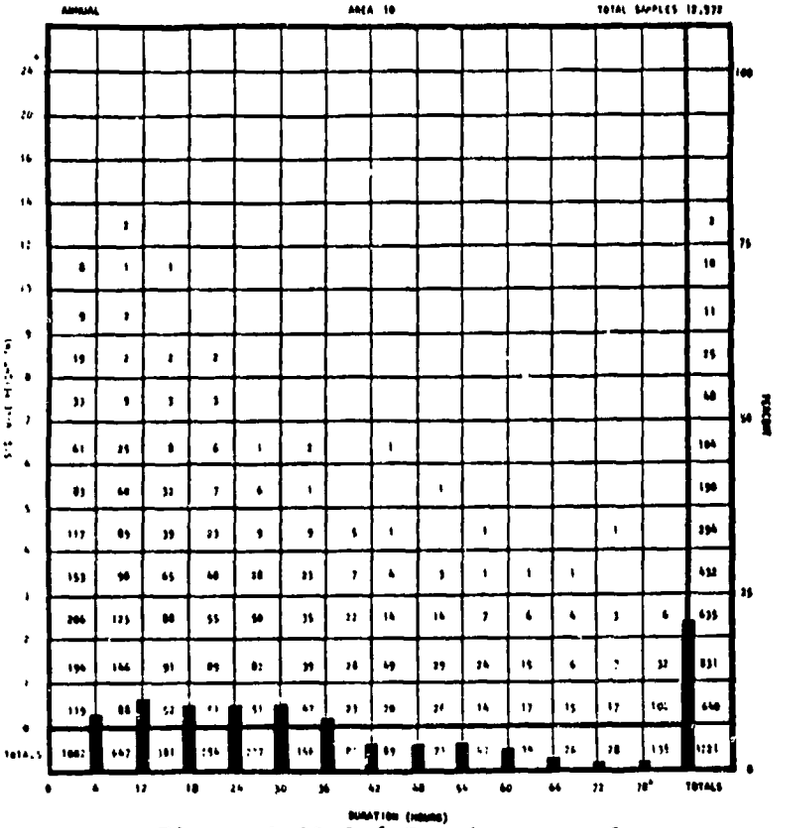


Figure A-10-1-6 Persistence of Significant Wave Height

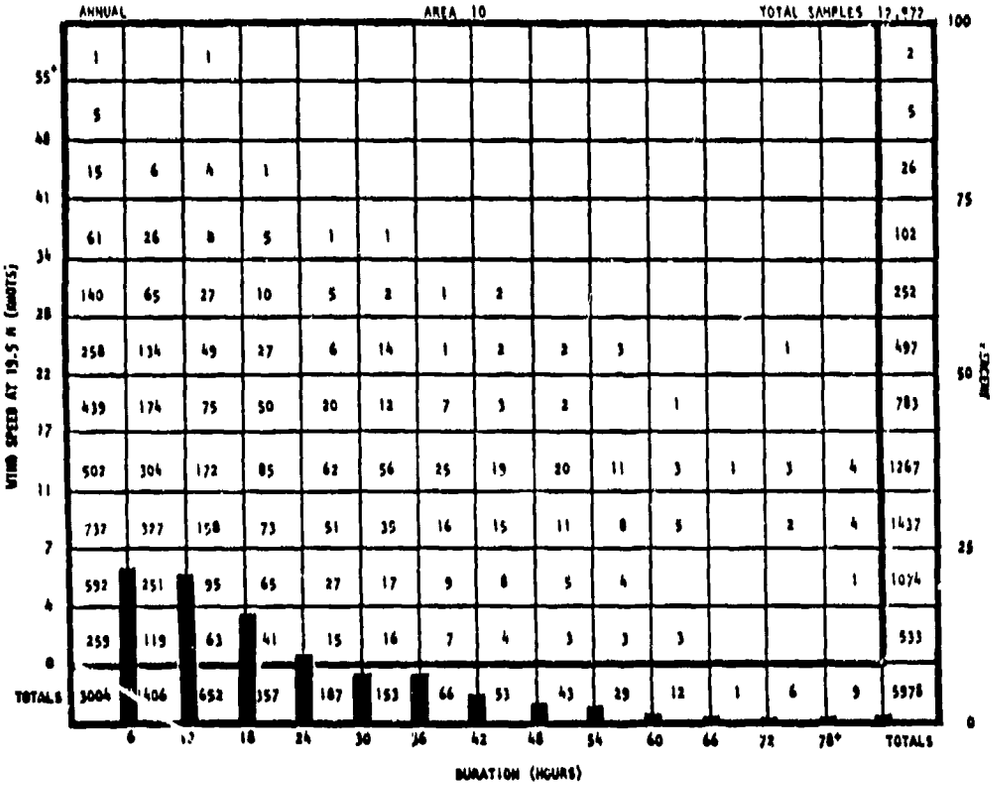


Figure A-10-1-7 Persistence of Wind Speed

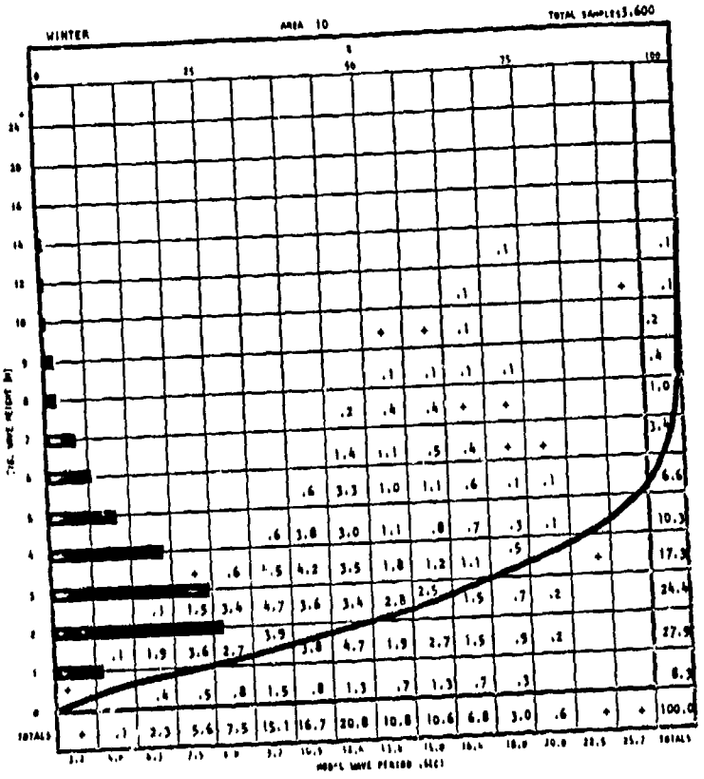


Figure A-10-2-1 Significant Wave Height by Modal Wave Period

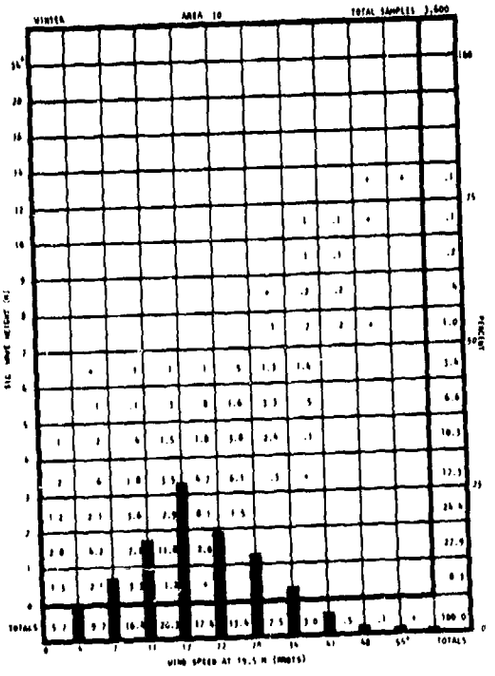


Figure A-10-2-2 Significant Wave Height by Wind Speed

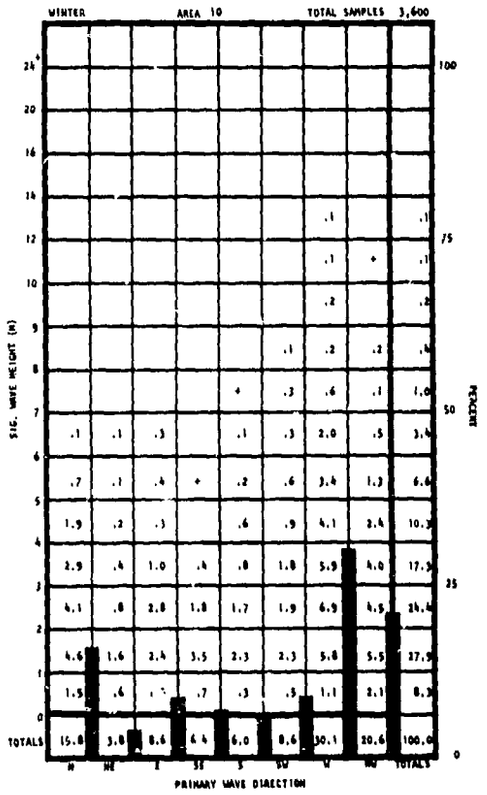


Figure A-10-2-3 Significant Wave Height by Wave Direction

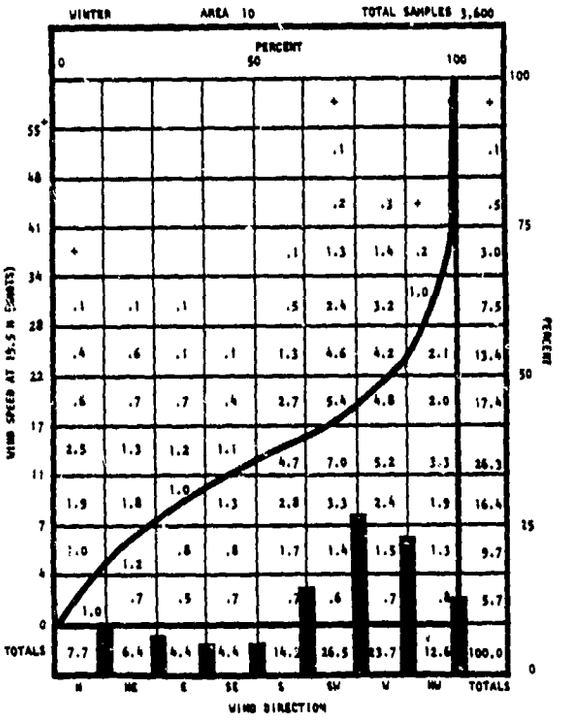


Figure A-10-2-4 Wind Speed by Wind Direction

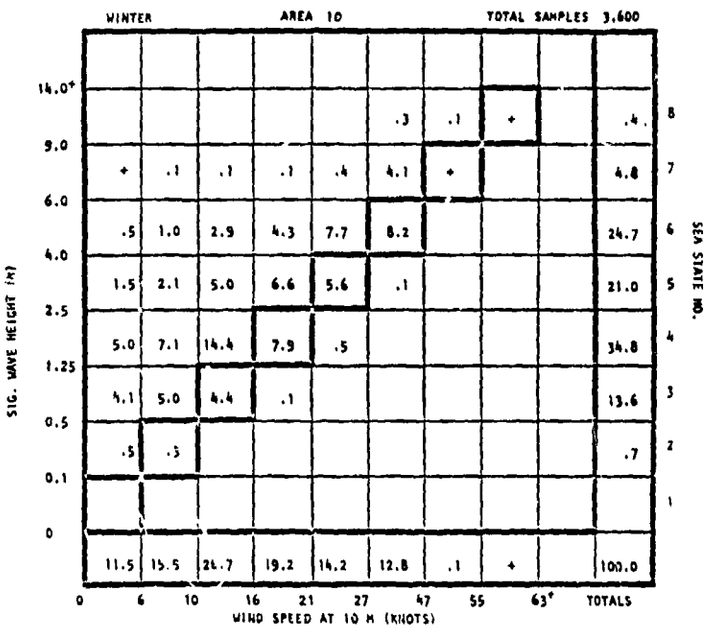


Figure A-10-2-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

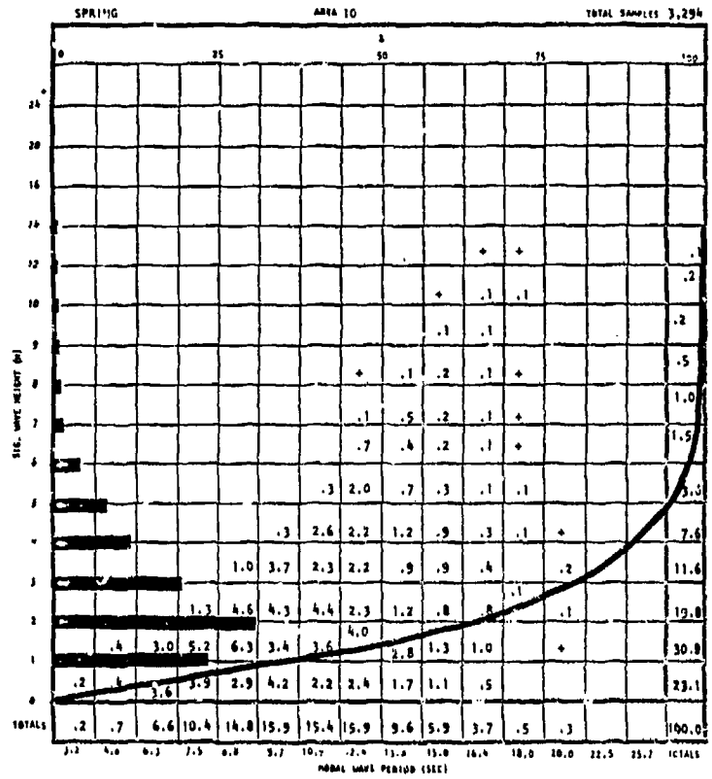


Figure A-10-3-1 Significant Wave Height by Modal Wave Period

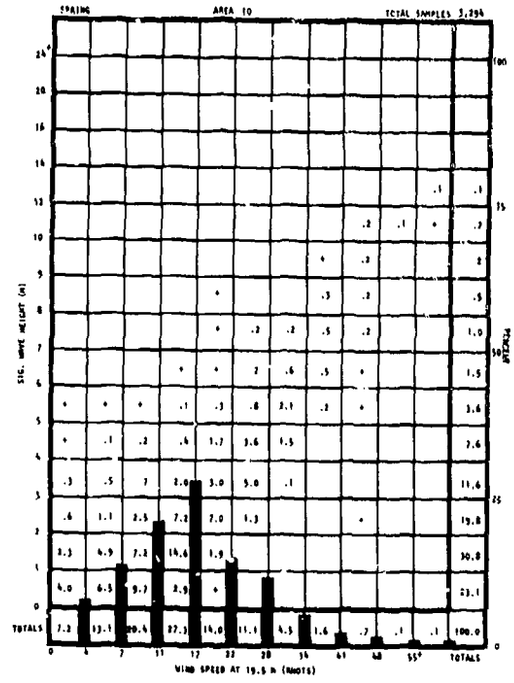


Figure A-10-3-2 Significant Wave Height by Wind Speed

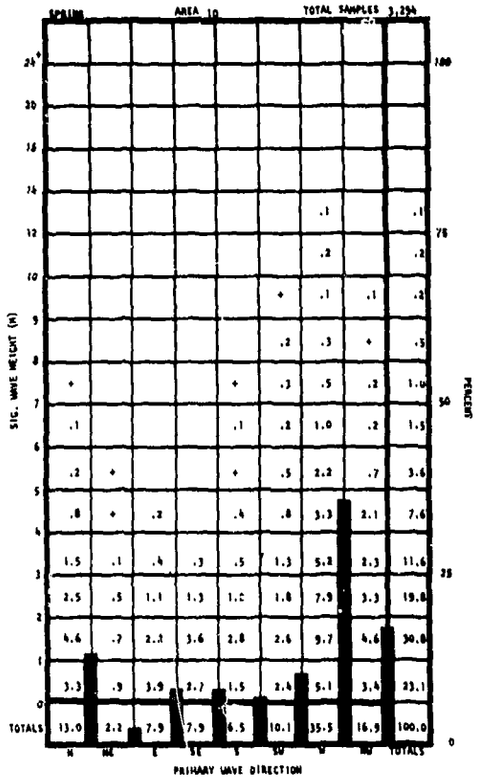


Figure A-10-3-3 Significant Wave Height by Wave Direction

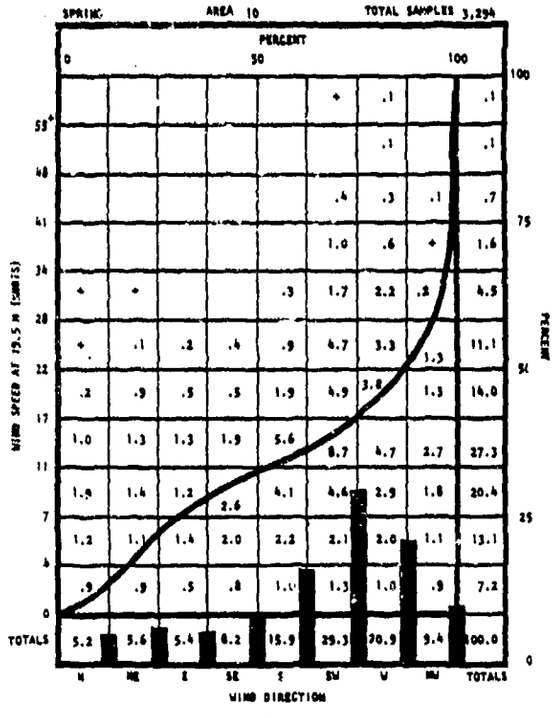


Figure A-10-3-4 Wind Speed by Wind Direction

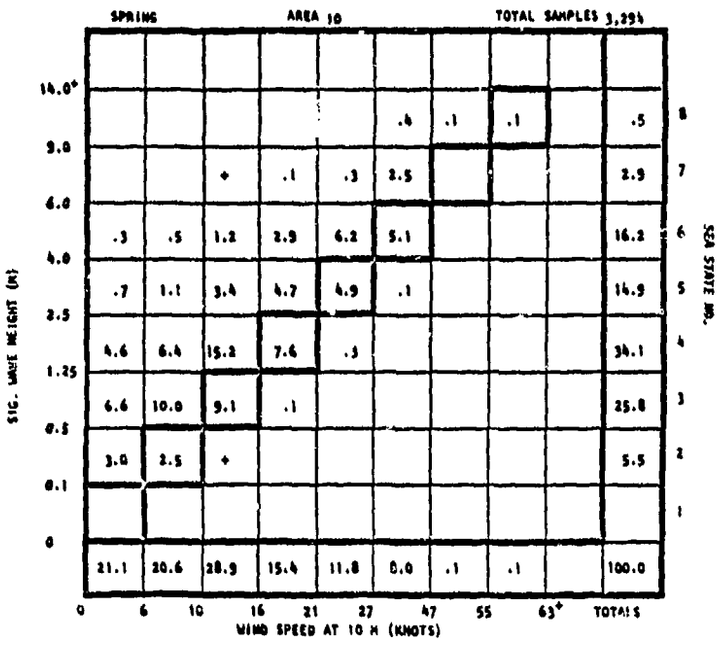


Figure A-10-3-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

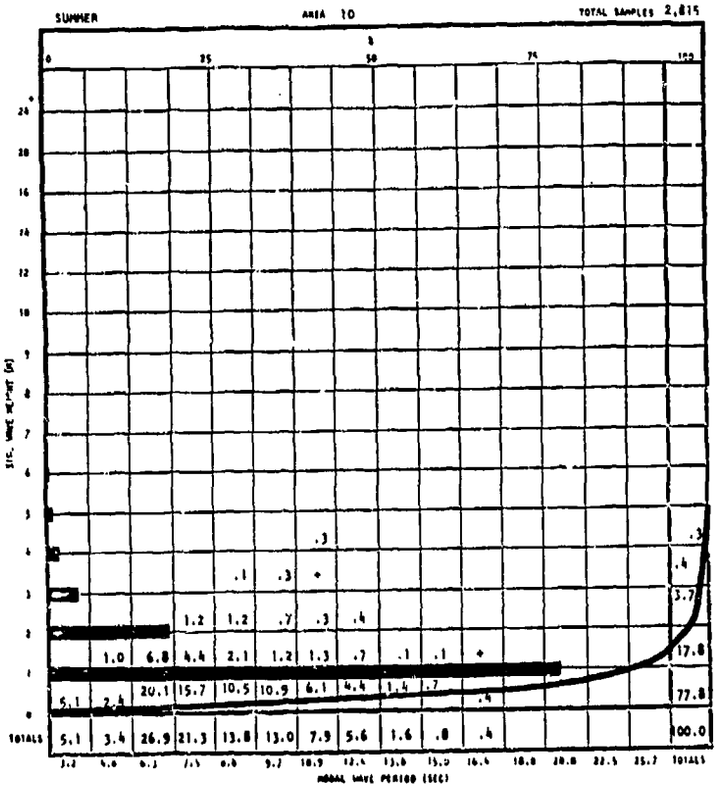


Figure A-10-4-1 Significant Wave Height by Modal Wave Period

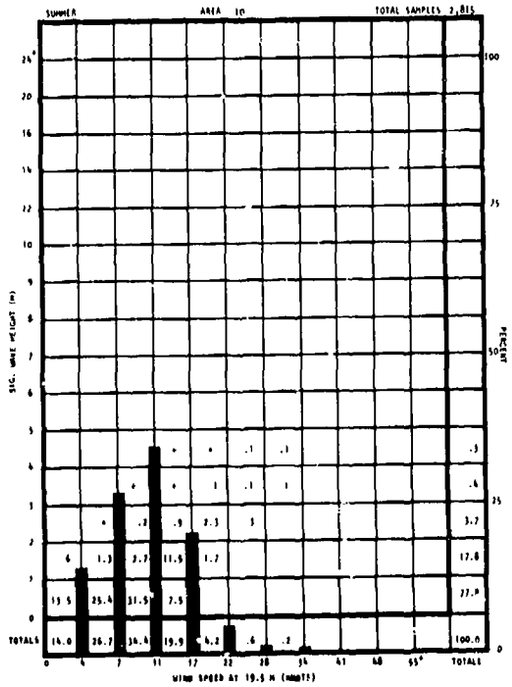


Figure A-10-4-2 Significant Wave Height by Wind Speed

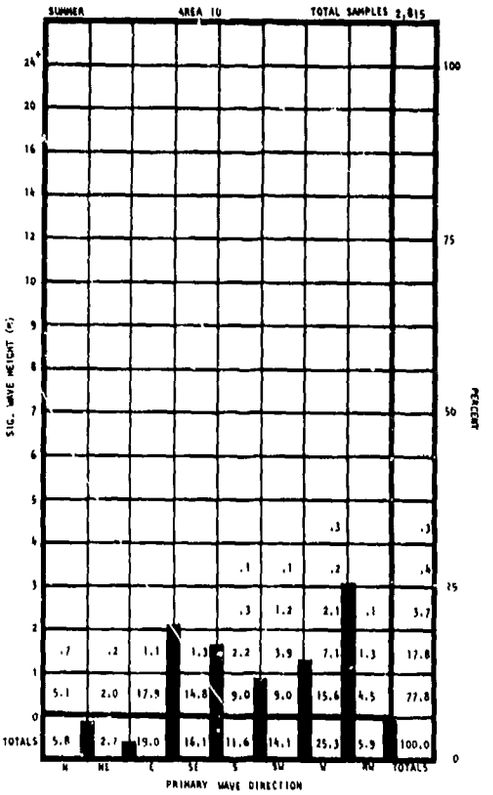


Figure A-10-4-3 Significant Wave Height by Wave Direction

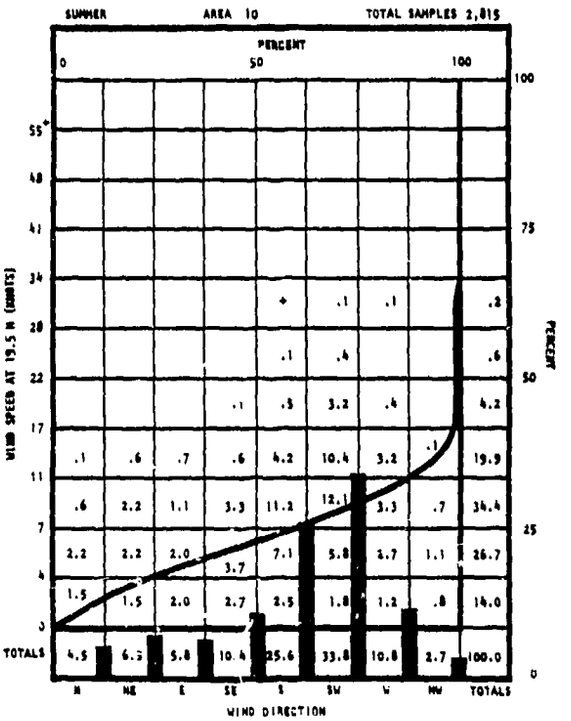


Figure A-10-4-4 Wind Speed by Wind Direction

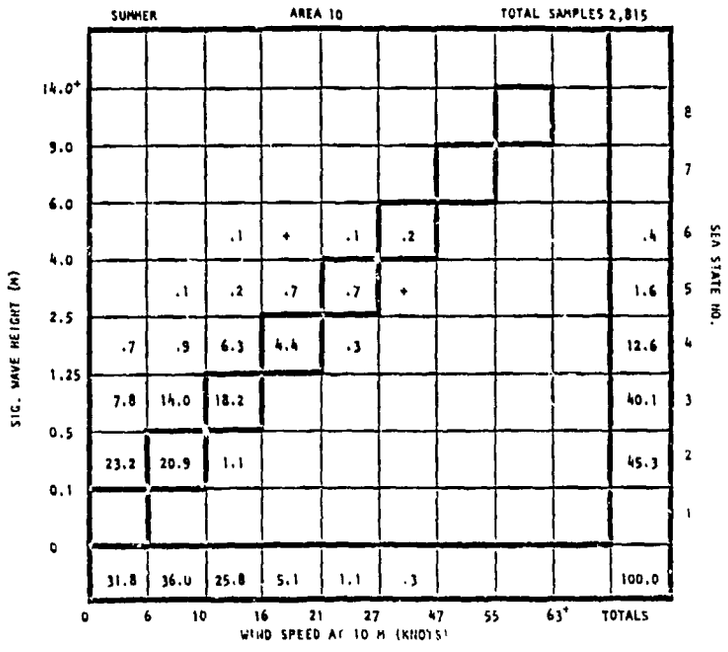


Figure A-10-4-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

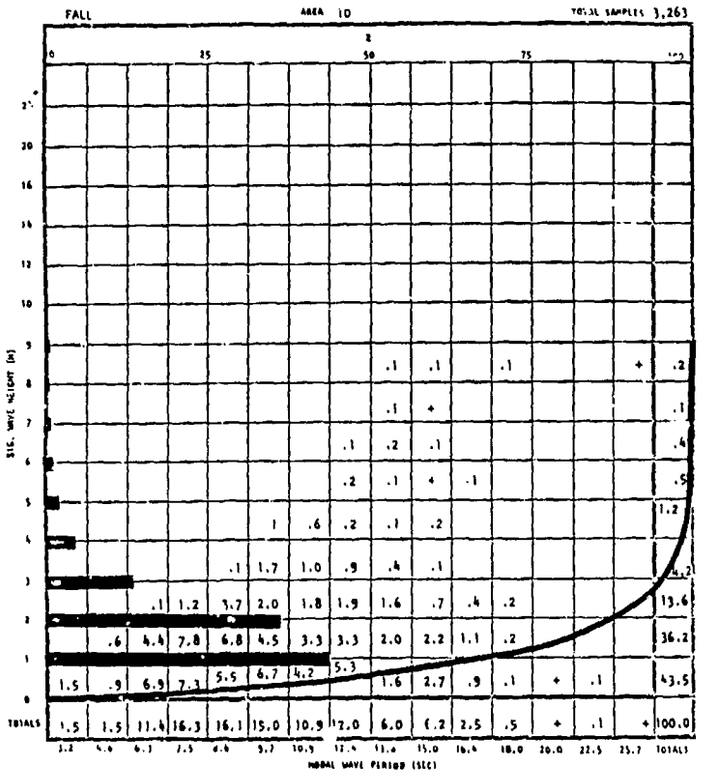


Figure A-10-5-1 Significant Wave Height by Modal Wave Period

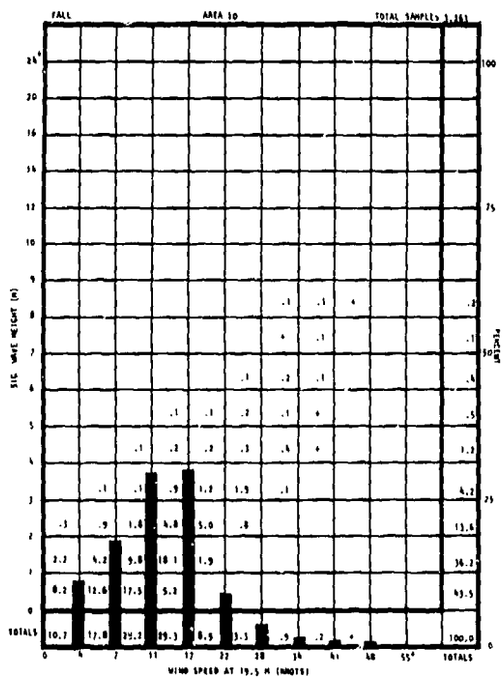


Figure A-10-5-2 Significant Wave Height by Wind Speed

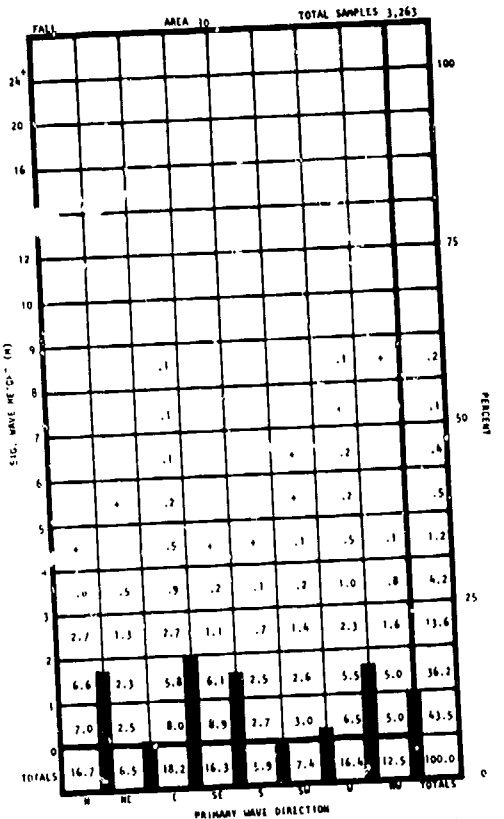


Figure A-10-5-3 Significant Wave Height by Wave Direction

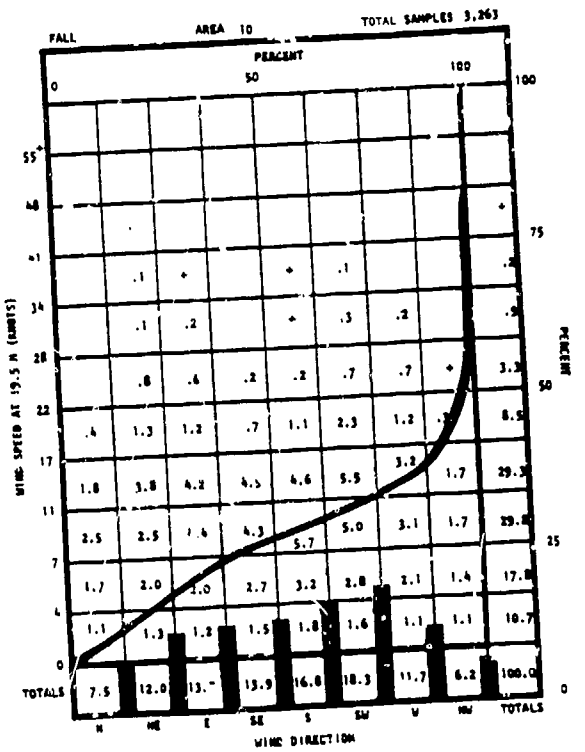


Figure A-10-5-4 Wind Speed by Wind Direction

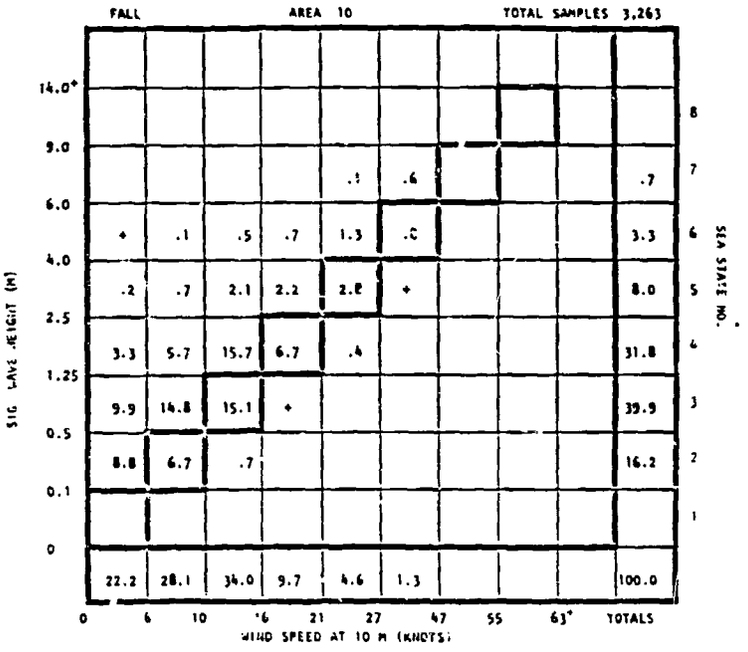


Figure A-10-5-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

TABLE A-11-1-1 - SURFACE NATURAL ENVIRONMENT SUMMARY

Season: Annual; Location: 39.912° N, 21.794° W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface Sig. Wave Height, m. Wave Period, sec Direction	.5 6 -	2 10 -	5.5 16 -	2.5 11 -	1.5 12 NW
Winds Speed, Knots Corresponding Mean Sig. Wave Height, m. Direction	3 1 -	12 2 -	28 5 -	13 2 -	14 2 W - NW
Visibility, nautical miles	5.5	17	25	-	-
Cloud Cover Total clouds, in eighths of sky obscured Low clouds, in eighths of sky obscured	Nil Nil	5 4	8 8	- -	- -
Precipitation (Occurrence)	All precipitation - 10% of the time		Snow - 1% of the time (Dec - Mar)		
Relative Humidity, %	60	80	96	-	-
Air Temperature, °C	13.5	17.5	23	17.5	-
Surface Water Temperature, °C	14	18	23	-	-
Sea Level Pressure, millibars	1,005	1,022	1,032	-	-
Ice	None				
Refractivity Mean Surface Refractivity Sub-Refraction (1 km, Annual) Super-Refraction or Ducting (1 km, Annual)	- - -	- - -	- - -	338 - -	- 5% of the time 2% of the time

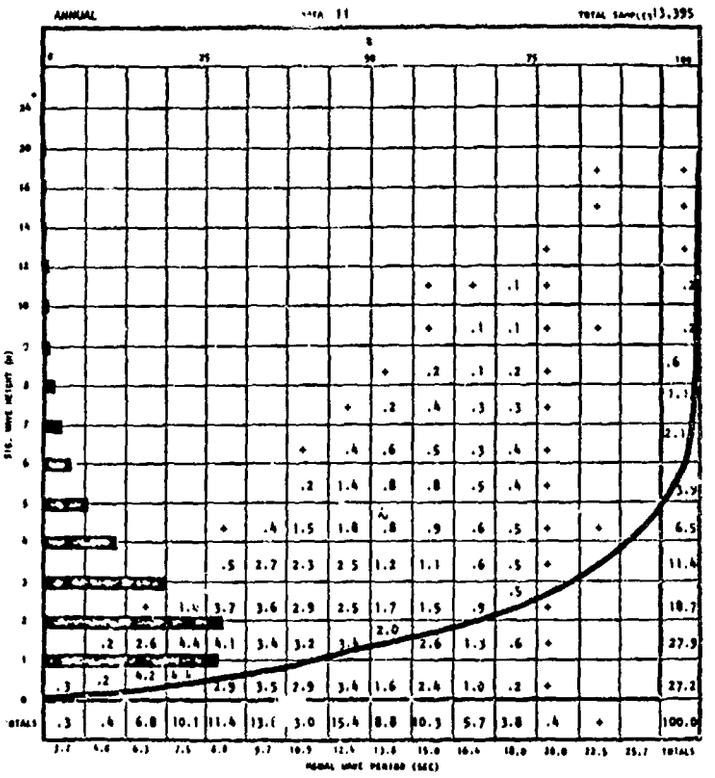


Figure A-11-1-1 Significant Wave Height by Modal Wave Period

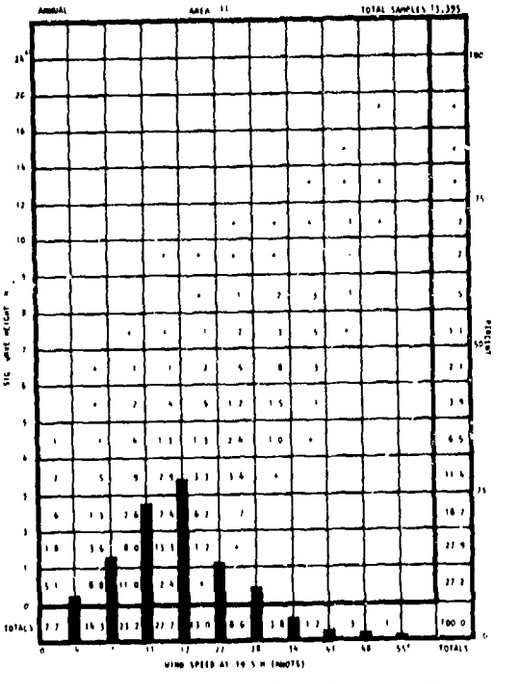


Figure A-11-1-2 Significant Wave Height by Wind Speed

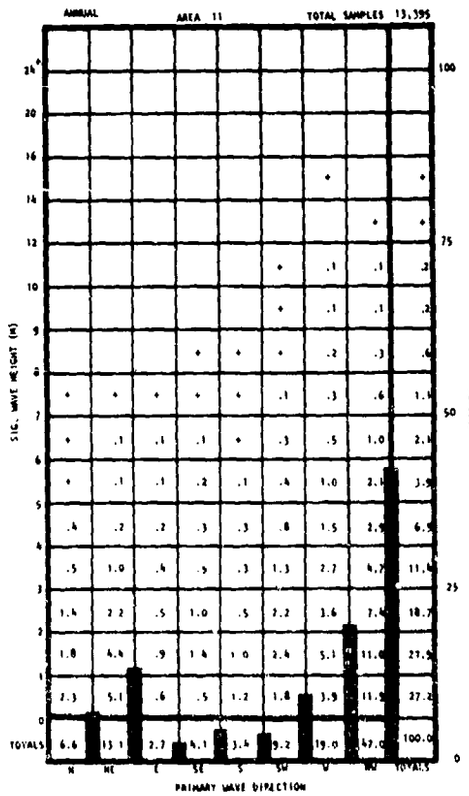


Figure A-11-1-3 Significant Wave Height by Wave Direction

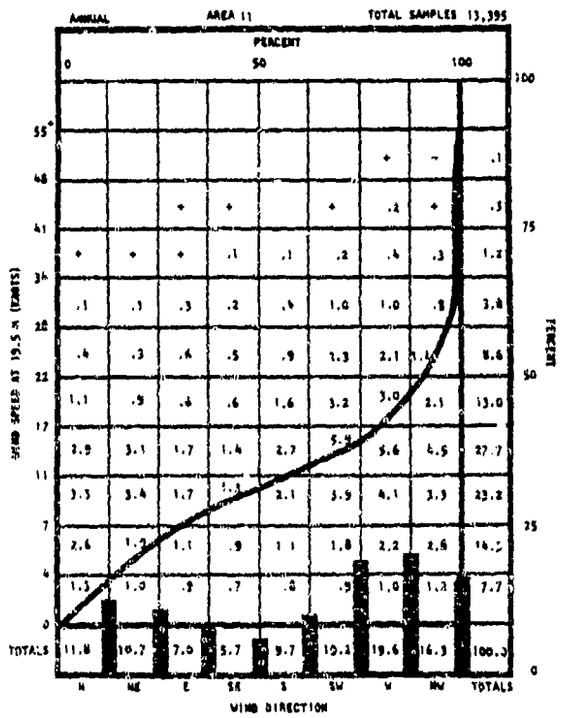


Figure A-11-1-4 Wind Speed by Wind Direction

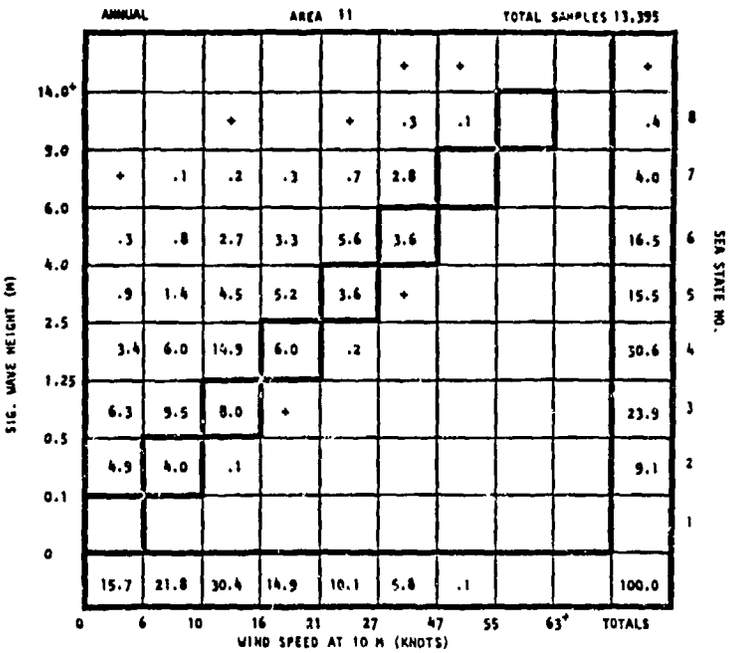


Figure A-11-1-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

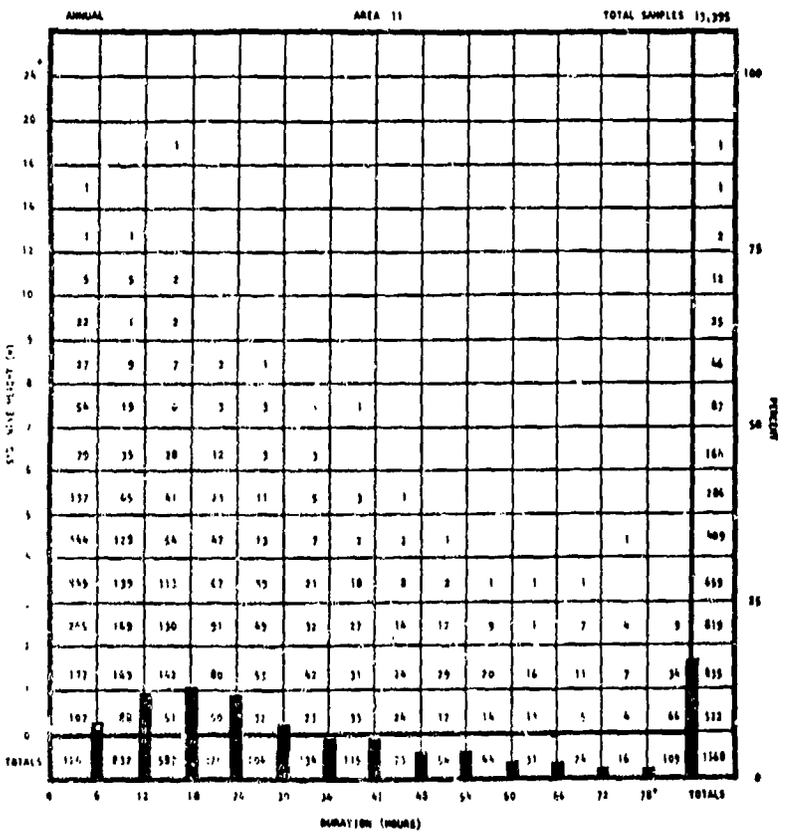


Figure A-11-1-6 Persistence of Significant Wave Height

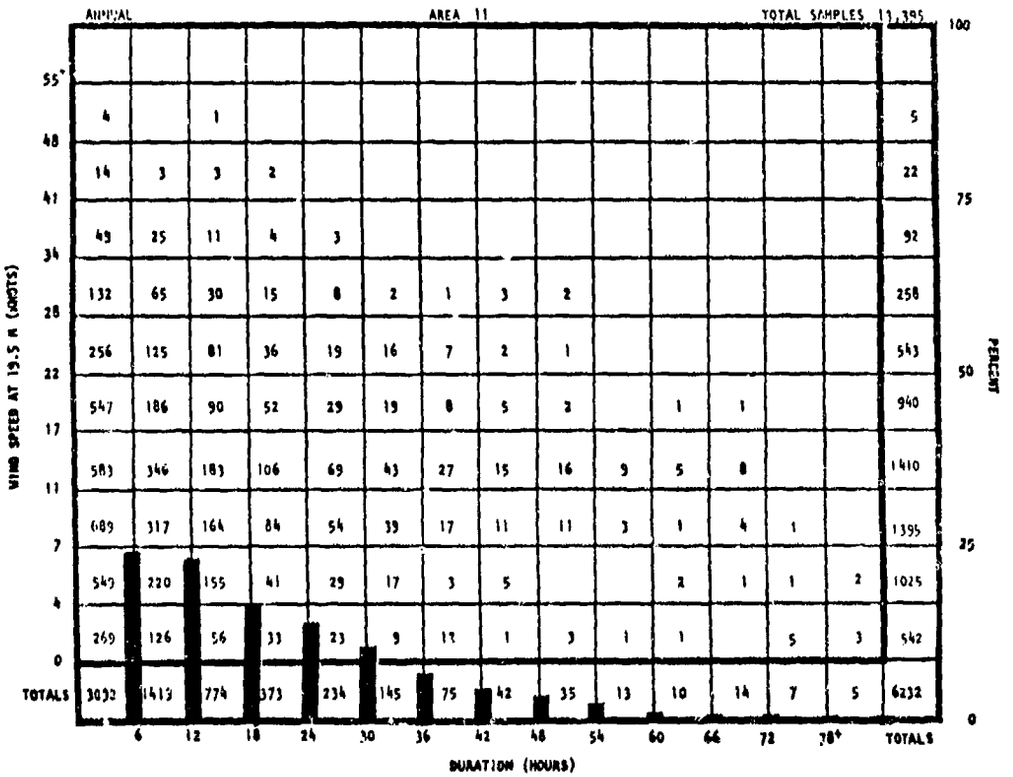


Figure A-11-1-7 Persistence of Wind Speed

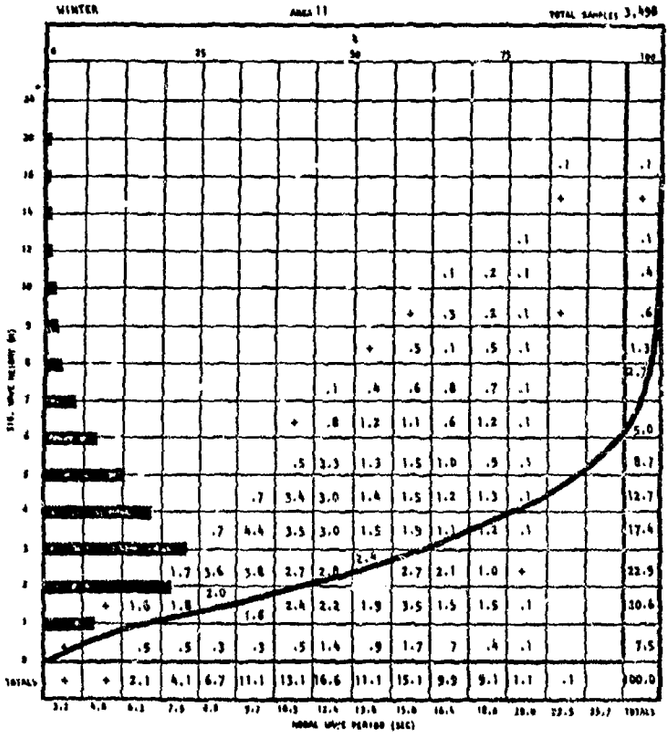


Figure A-11-2-1 Significant Wave Height by Modal Wave Period

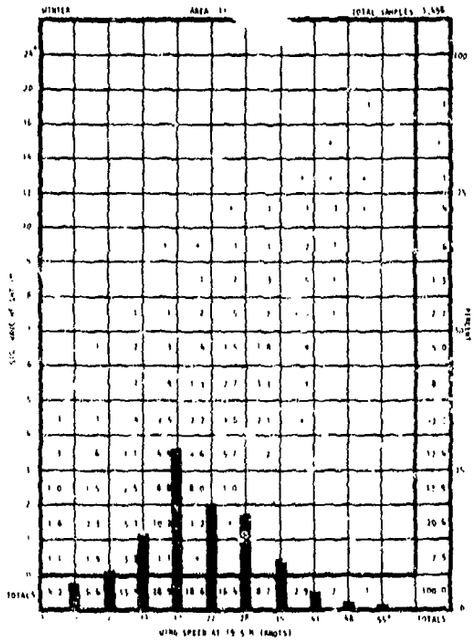


Figure A-11-2-2 Significant Wave Height by Wind Speed

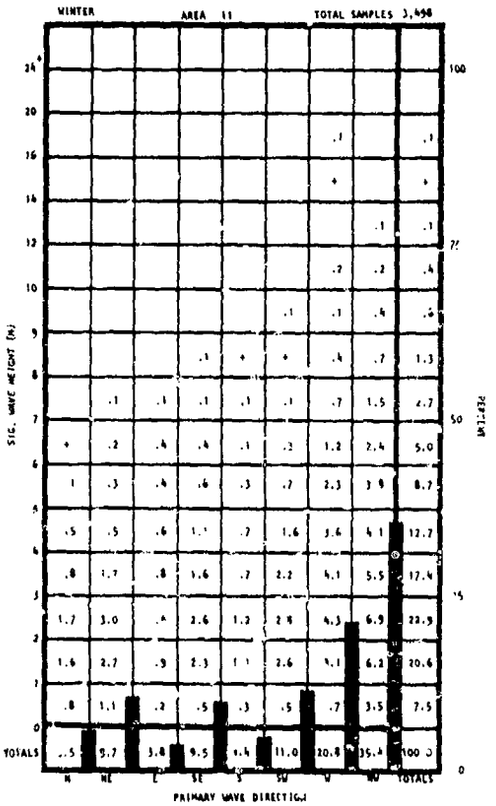


Figure A-11-2-3 Significant Wave Height by Wave Direction

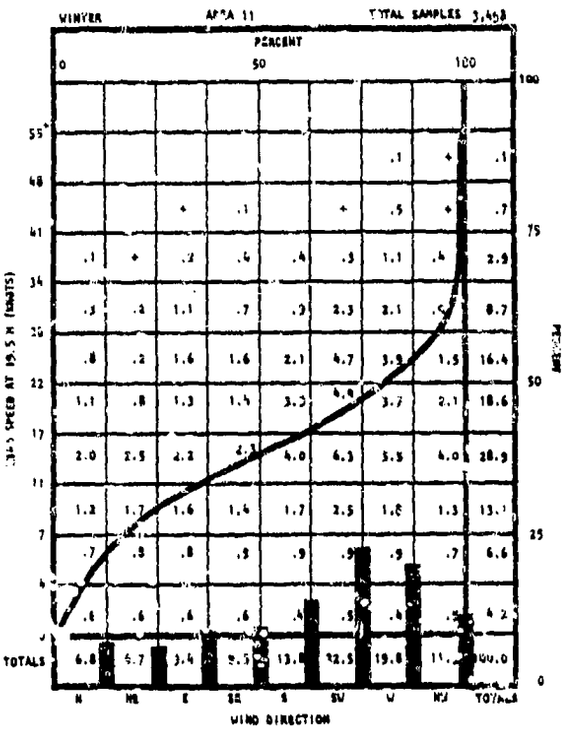


Figure A-11-2-4 Wind Speed by Wind Direction

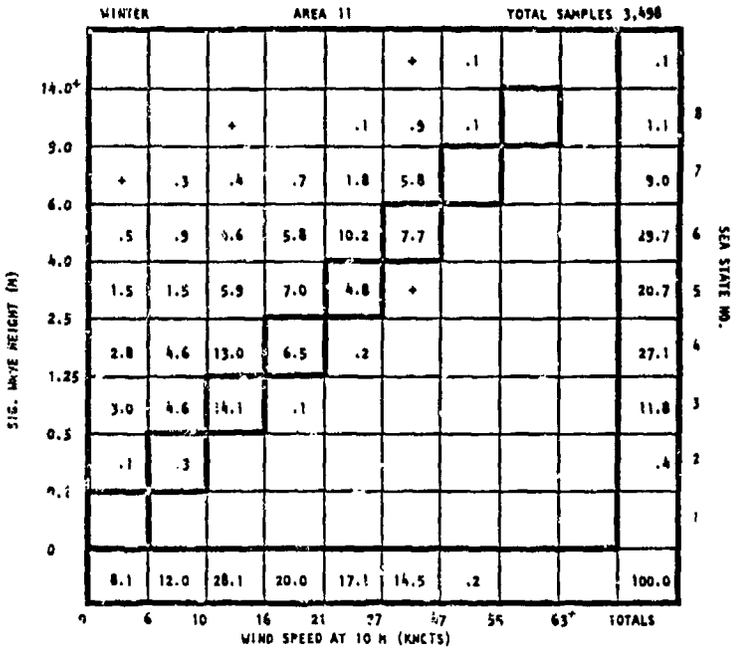


Figure A-11-2-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

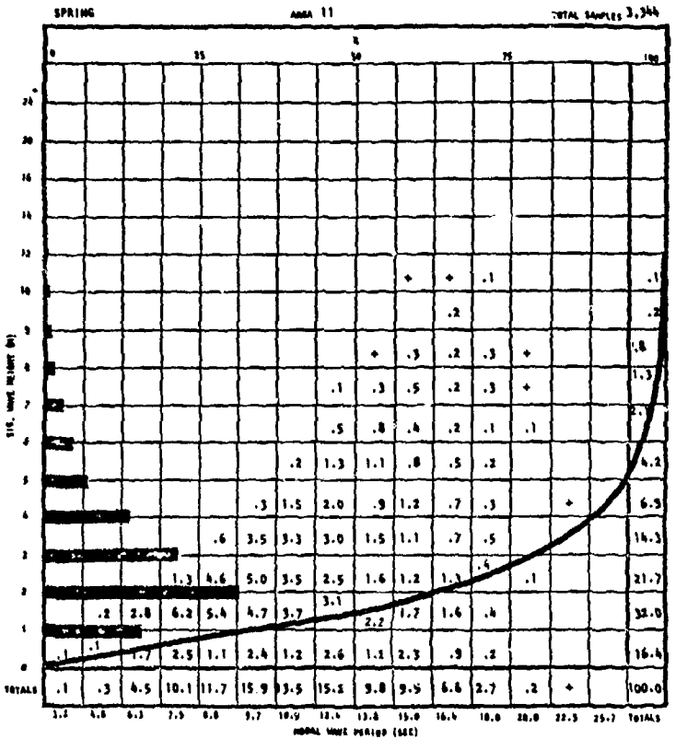


Figure A-11-3-1 Significant Wave Height by Modal Wave Period

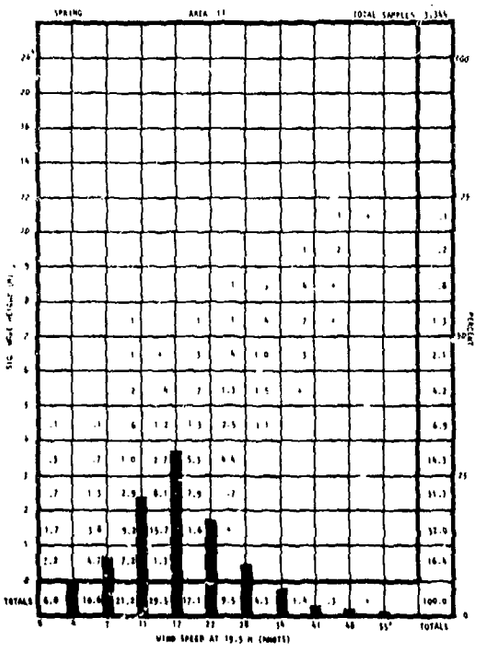


Figure A-11-3-2 Significant Wave Height by Wind Speed

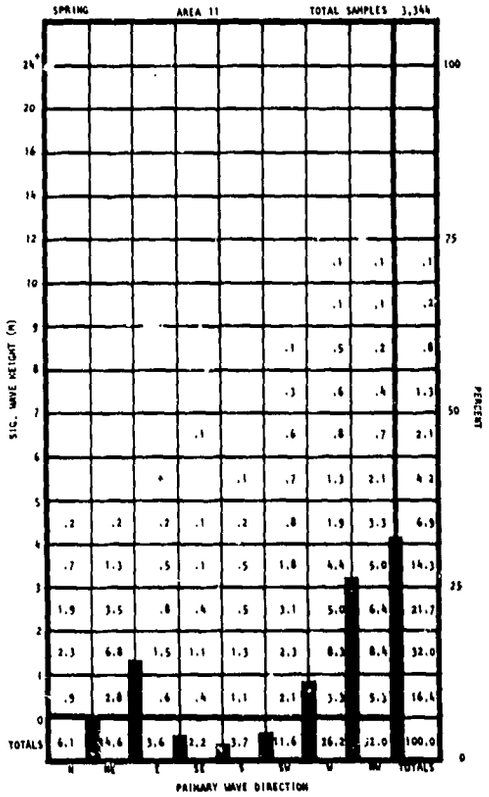


Figure A-11-3-3 Significant Wave Height by Wave Direction

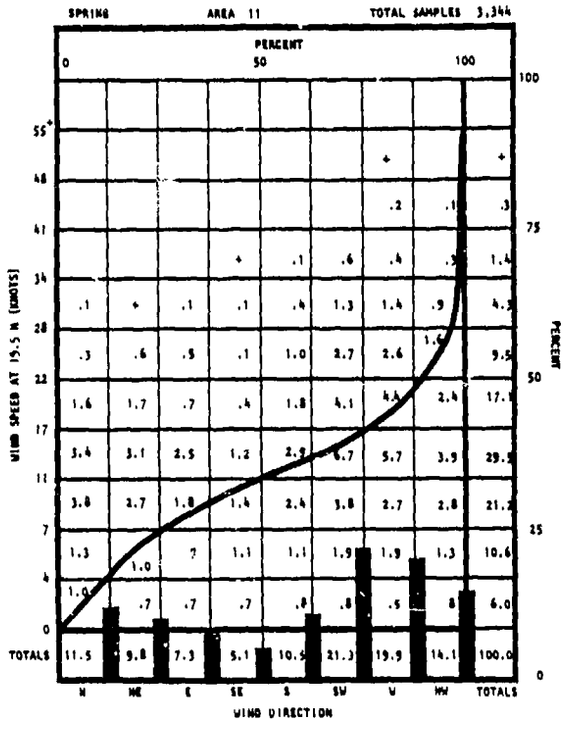


Figure A-11-3-4 Wind Speed by Wind Direction

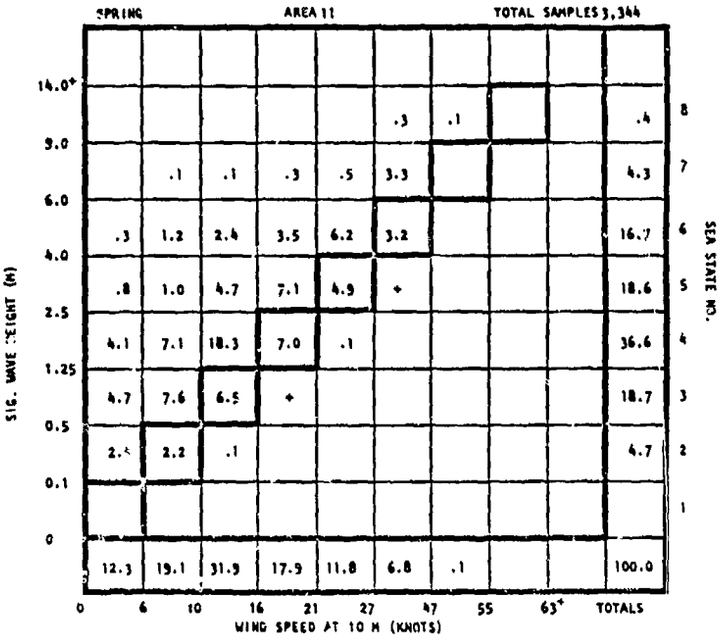


Figure A-11-3-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)

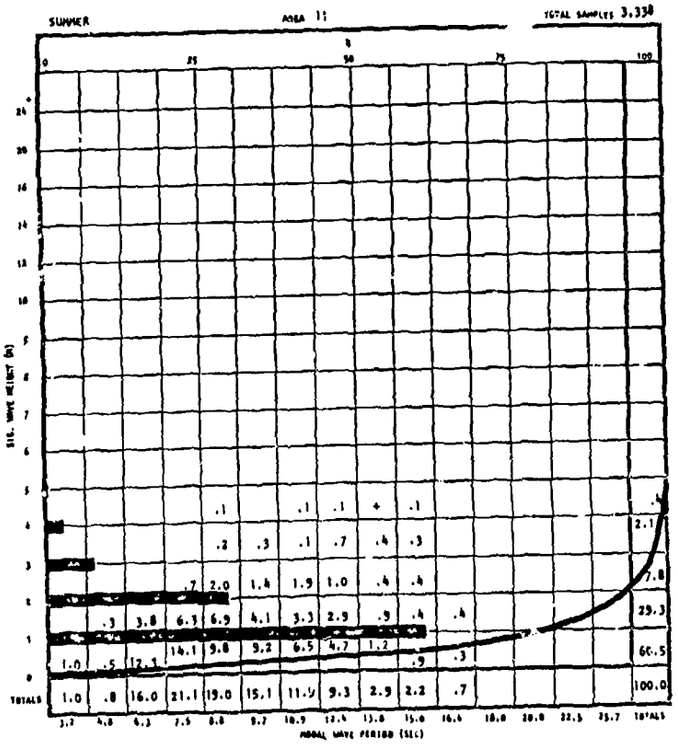


Figure A-11-4-1 Significant Wave Height by Modal Wave Period

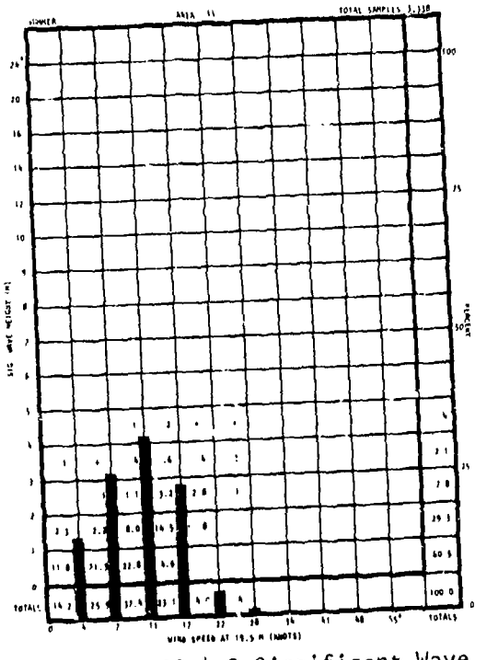


Figure A-11-4-2 Significant Wave Height by Wind Speed

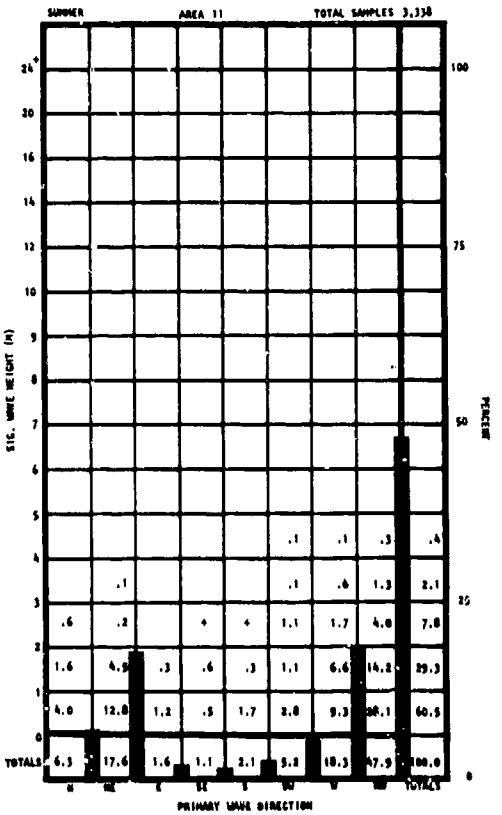


Figure A-11-4-3 Significant Wave Height by Wave Direction

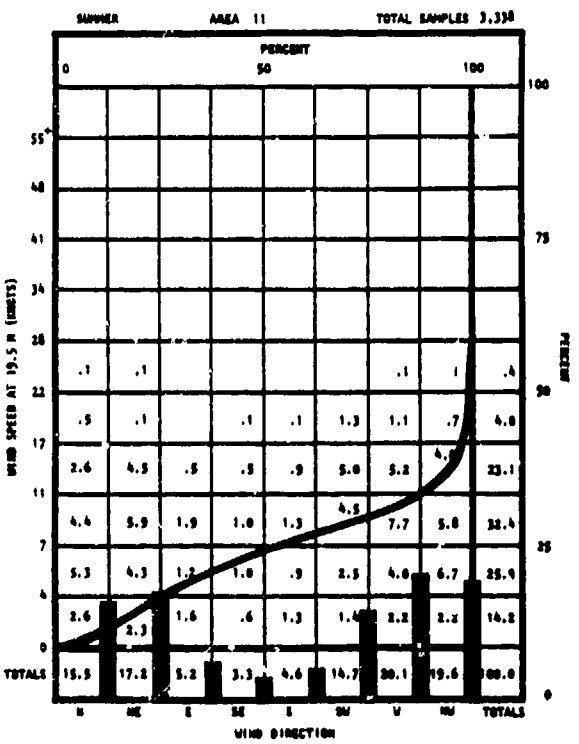


Figure A-11-4-4 Wind Speed by Wind Direction

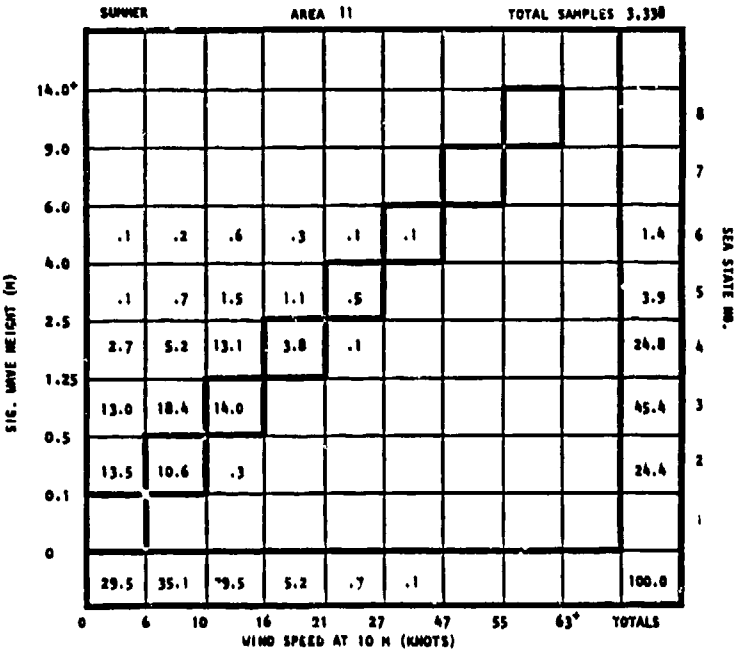


Figure A-11-4-5 Significant Wave Height by Wind Speed (WMO Sea State Chart)